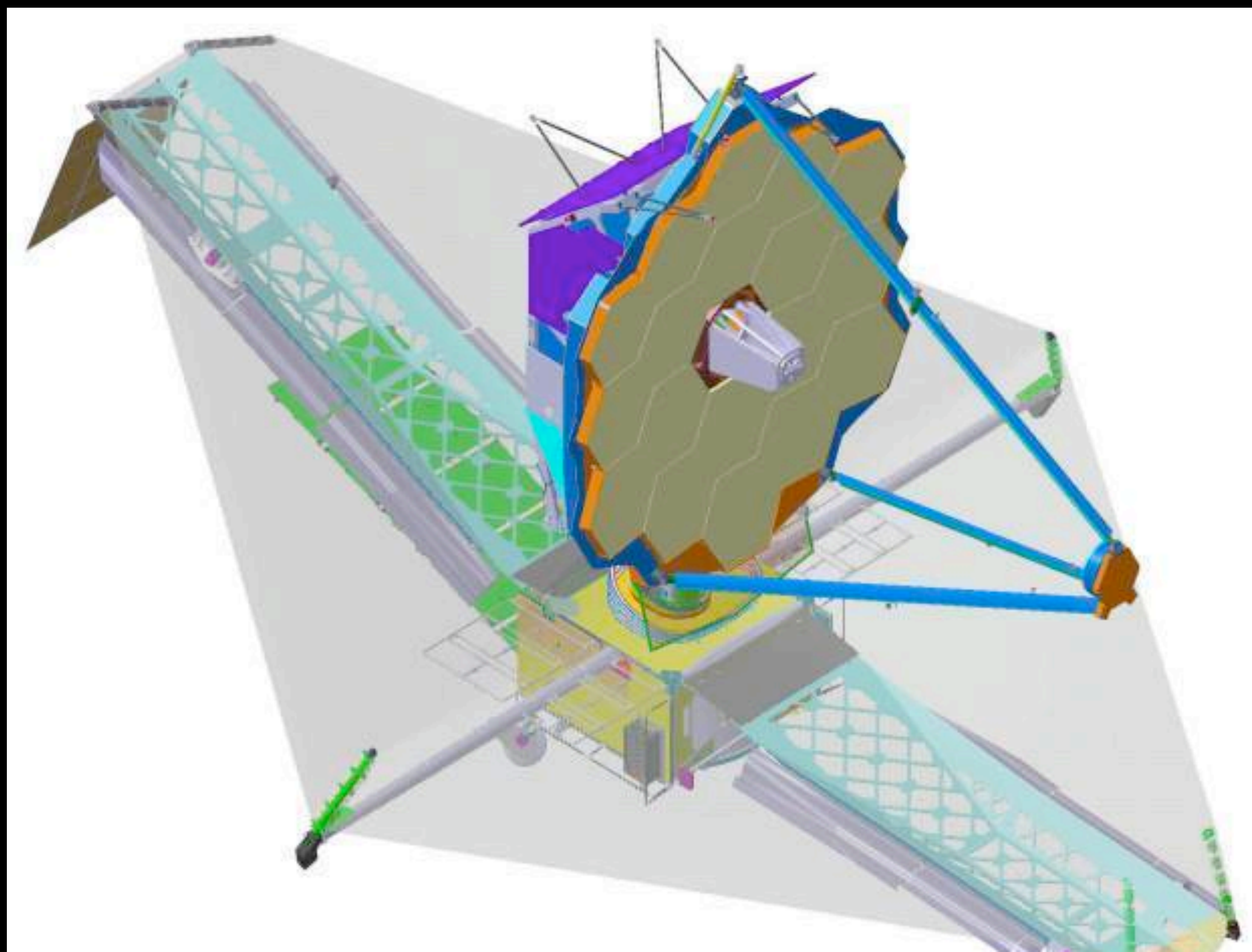
Space Telescope

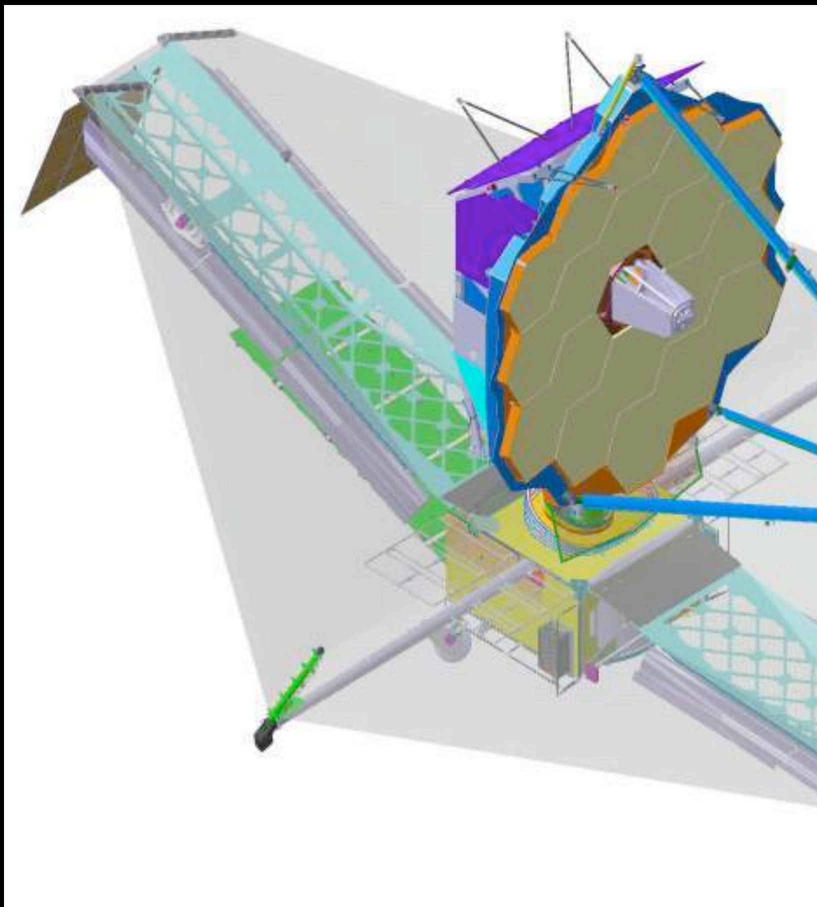
John Mather, NASA‘s GSFC

January 10, 2009



Organization

on Lead: Goddard Space Flight Center
national collaboration with ESA & CSA
e Contractor: Northrop Grumman Space
nology
uments:
ear Infrared Camera (NIRCam) – Univ. of Arizona
ear Infrared Spectrograph (NIRSpec) – ESA
id-Infrared Instrument (MIRI) – JPL/ESA
ne Guidance Sensor (FGS) – CSA
ations: Space Telescope Science Institute



Description

able infrared telescope with 6.5
diameter segmented adjustable
y mirror

enic temperature telescope and
nents for infrared performance

2013 on an ESA-supplied Ariane
et to Sun-Earth L2

JWST Science Themes


End of the dark


The assembly of


Birth of stars and

F

6 Interdisciplinary Scientists: H. Hammel, S. Lilly, J. Lunine, M. McCaughrean, M. Stiavelli, R. Windhorst

Instrument Team Lead/ Science Representative: M. Rieke (NIRCam), G. Rieke and G. Wright (MIRI), Rene Doyon (FGS), & rotating scientist member, NIRSpec

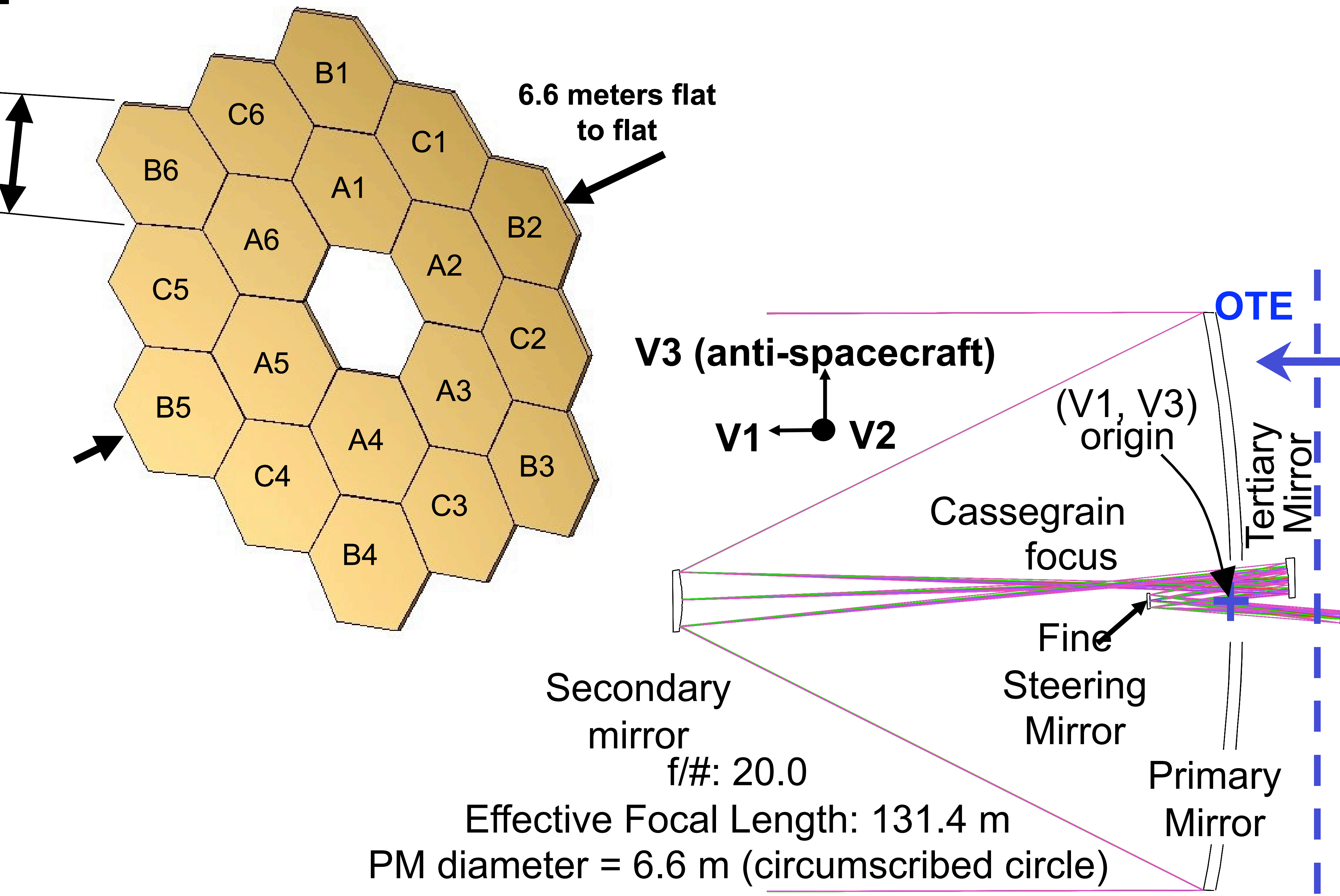
Telescope Scientist: M. Mountain (also STScI Director)

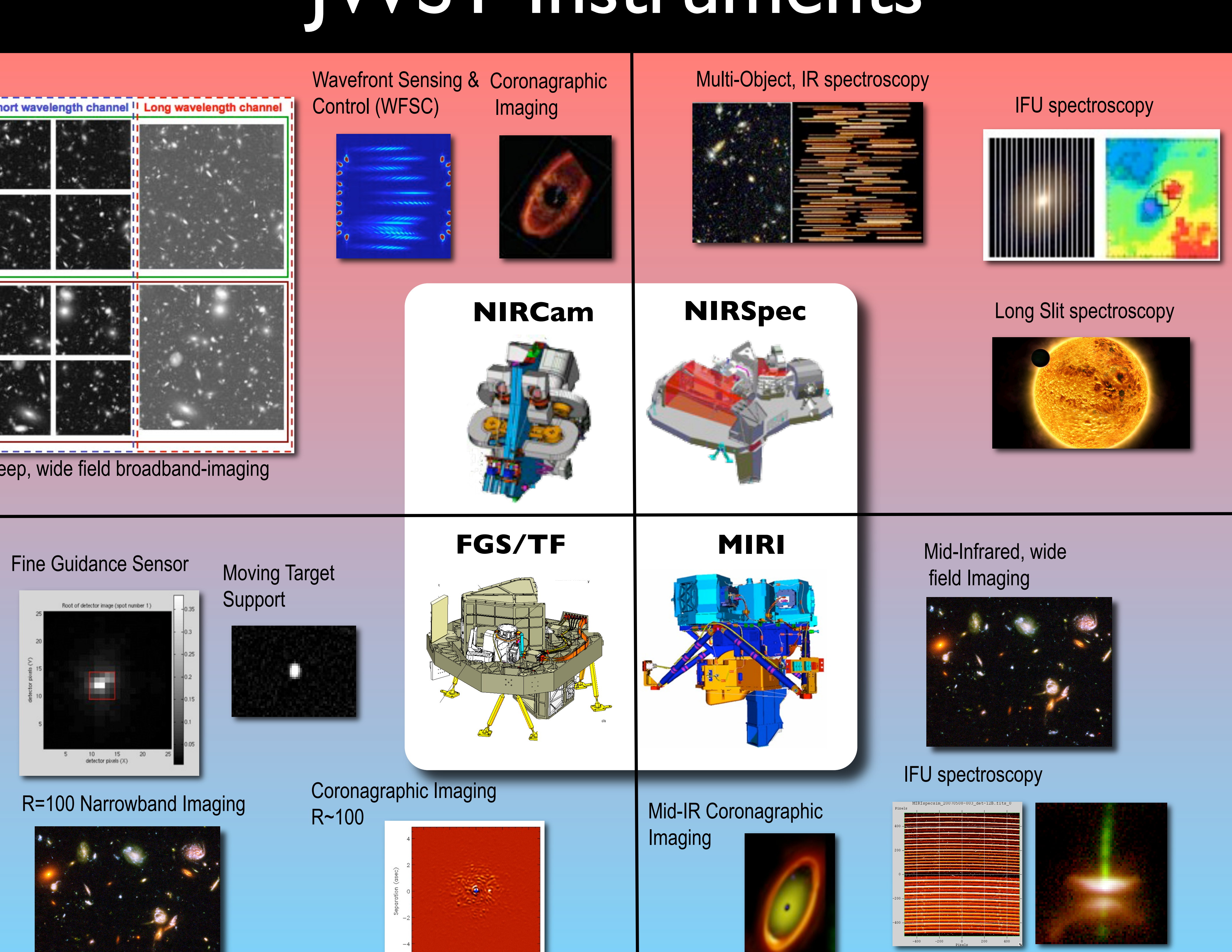
Ex Officio: J. Mather (Chair), J. Gardner, M. Clampin, M. Greenhous K. Flanagan, G. Sonneborn, P. Jakobsen, J. Hutchings

Project Summary Document

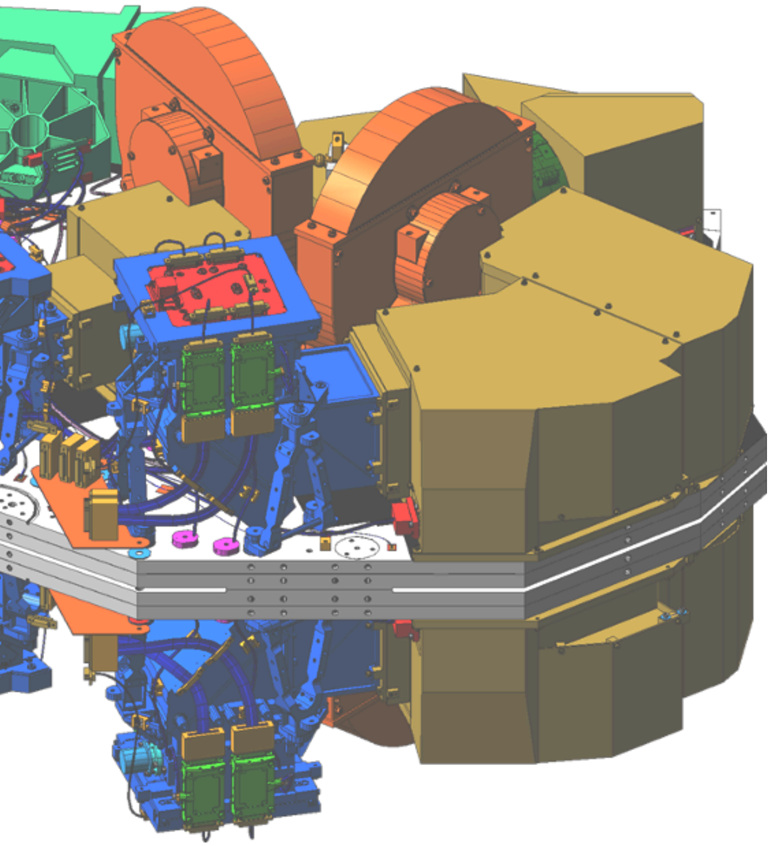
Gardner et al. 2006, Space Science Reviews, 123/4, 485 http://jwst.gsfc.nasa.gov/scientists.html

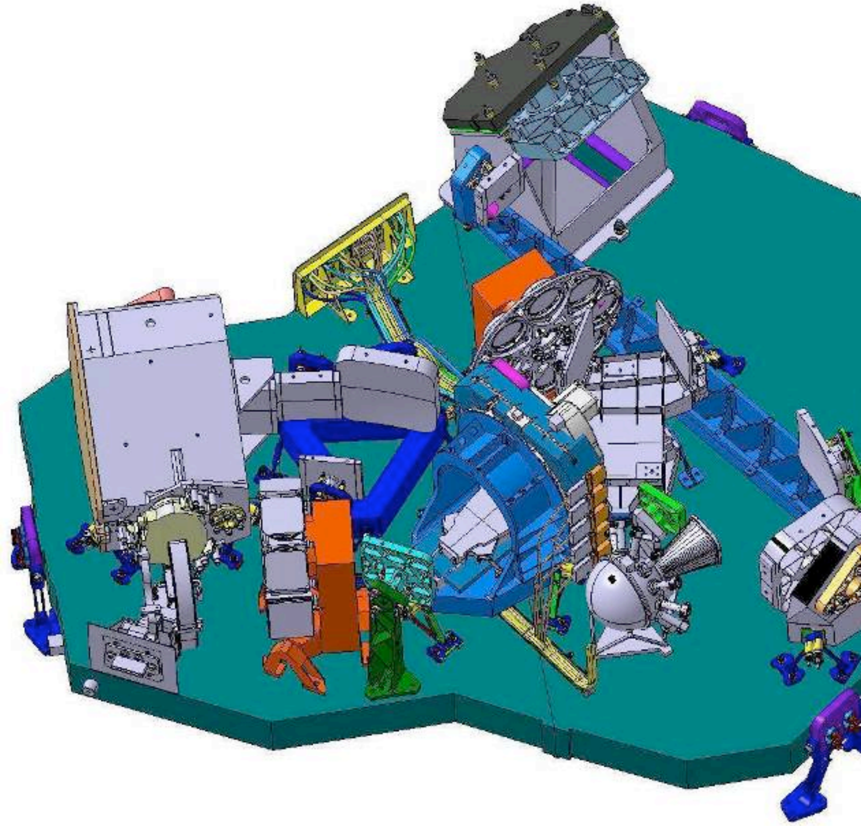
Provides a Wide Field-of-View

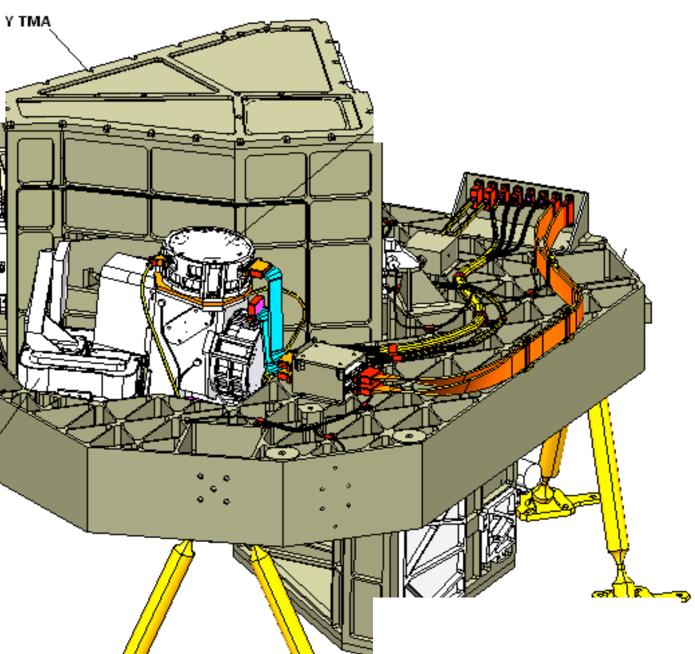




ort wavelength channel
Long wavelength channel
eep, wide field broadband-imaging
Wavefront Sensing &
Control (WFSC)
Coronagraphic
Imaging
Multi-Object, IR spectroscopy
IFU spectroscopy
Long Slit spectroscopy
NIRCam
NIRSpec
FGS/TF
MIRI
Fine Guidance Sensor
Moving Target
Support
R=100 Narrowband Imaging
Coronagraphic Imaging
R~100
Mid-Infrared, wide
field Imaging
Mid-IR Coronagraphic
Imaging
IFU spectroscopy



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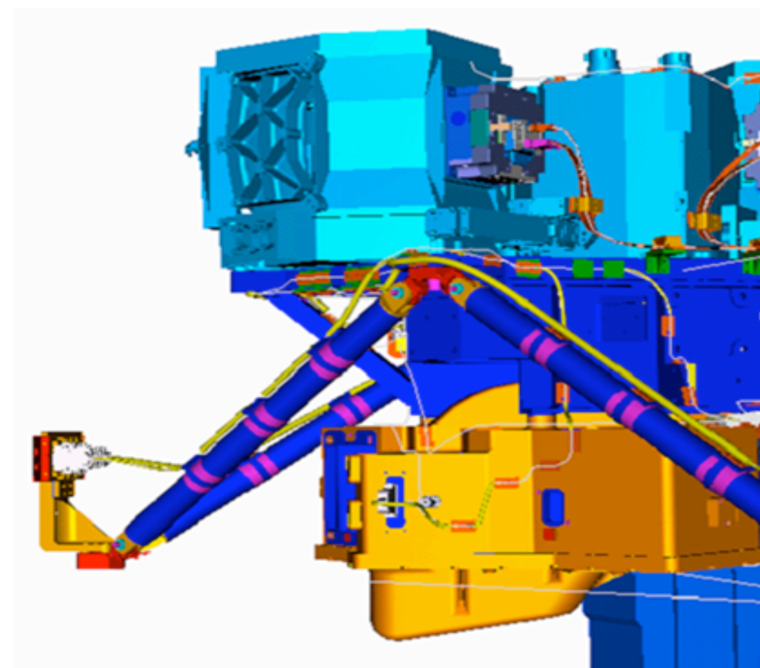
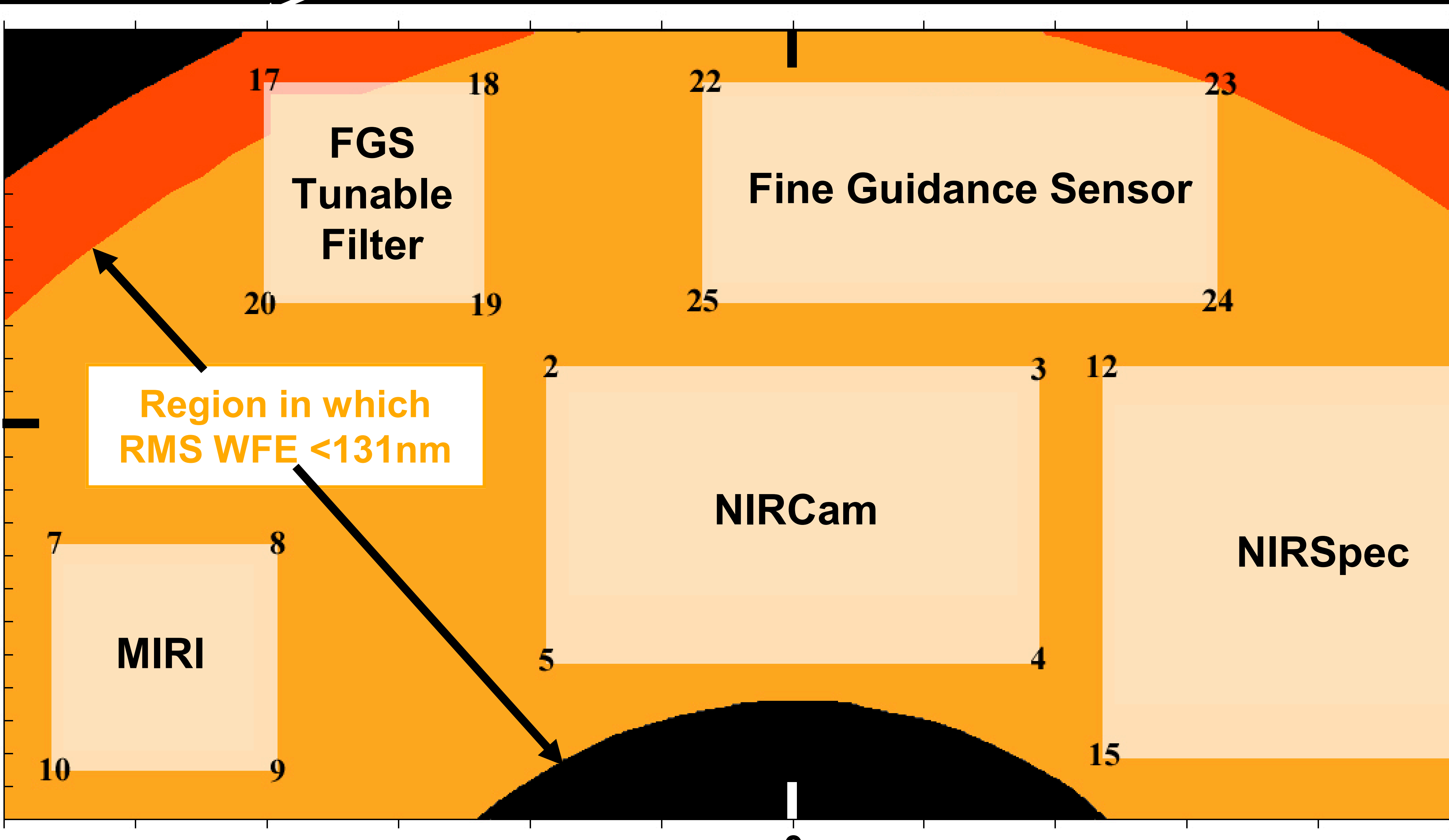


Field Position of Science Instrument

Boundary of Unvignetted field



Instruments and Guidance Sensor Share Telescope Field of View

- Cameras and R ~ 100 spectroscopy background limited at all wavelengths
  - 6.5 m mirror much larger than HST, Spitzer - big gains
  - Background dominated by zodi light, and at > 12 μm from thermal emission from sunshield
  - Other stray light from galaxy, sometimes Earth or Moon
- NIRSpec sensitivity detector limited at R ~ 1000
- Image quality
  - Diffraction limited (λ/14 rms wavefront) at 2 μm (~ ground AO)
  - 0.034 arcsec pixels in NIRCam short band (Nyquist @ 2 μm)
  - 0.068 arcsec in NIRCam long band and Fine Guider
  - 0.2 x 0.45 arcsec shutters for NIRSpec
  - 0.11 arcsec pixels for MIRI camera
  - 0.19 - 0.28 arcsec pixels for MIRI image slicer integral field unit

Instrument	Wavelength(μm)	Detector	Plate scale (milliarcsec/pixel)	Field of view
NIRCam			32	2.2×4.4 arcm
Short	0.6–2.3	Eight 2048×2048		
Long[a]	2.4–5.0 2048×2048	Two	65	2.2×4.4 arcm
NIRSpec	0.6–5.0	Two	100	
MSA[b]			2048×2048	3.4×3.1 arcm
Slits[c]				$\sim 0.2 \times 4$ arcs
IFU				3.0×3.0 arcs
MIRI	5.0–29.0	1024×1024	110	
Imaging				1.4×1.9 arcm
Coronagraphy				26×26 arcsec
Spectra[d]	5.0–10.0			0.2×5 arcsec
IFU	5.0–29.0	Two 1024×1024	200 to 470	3.6×3.6 to 7.5×7.5 ar
TFI	1.6–4.9[e]	2048×2048	65	2.2×2.2 arcm

[b]NIRSpec includes a microshutter assembly (MSA) with four 365×171 microshutter
The individual shutters are each 203 (spectral) $\times$ 463 (spatial) milliarcsec clear apertur
267×528 milliarcsec pitch.

JWST Sensitivities

TABLE X

Instrument sensitivities

Instrument/mode	λ (μm)	Bandwidth	Sensitivity
NIRCam	2.0	$R = 4$	11.4 nJy, AB = 28.8
TFI	3.5	$R = 100$	126 nJy, AB = 26.1
NIRSpec/Low Res.	3.0	$R = 100$	132 nJy, AB = 26.1
NIRspec/Med. Res.	2.0	$R = 1000$	1.64×10^{-18} erg s^{-1} cm^{-2}
MIRI/Broadband	10.0	$R = 5$	700 nJy, AB = 24.3
MIRI/Broadband	21.0	$R = 4.2$	8.7 μJy, AB = 21.6
MIRI/Spect.	9.2	$R = 2400$	1.0×10^{-17} erg s^{-1} cm^{-2}
MIRI/Spect.	22.5	$R = 1200$	5.6×10^{-17} erg s^{-1} cm^{-2}

Note. Sensitivity is defined to be the brightness of a point source detected at 10σ in 10,000 s. Longer or shorter exposures are expected to scale approximately as the square root of the exposure time. Targets at the North Ecliptic Pole are assumed. The sensitivities in this table represent the best estimate at the time of submission and are subject to change.

TABLE II

JWST measurements for the end of the dark ages theme

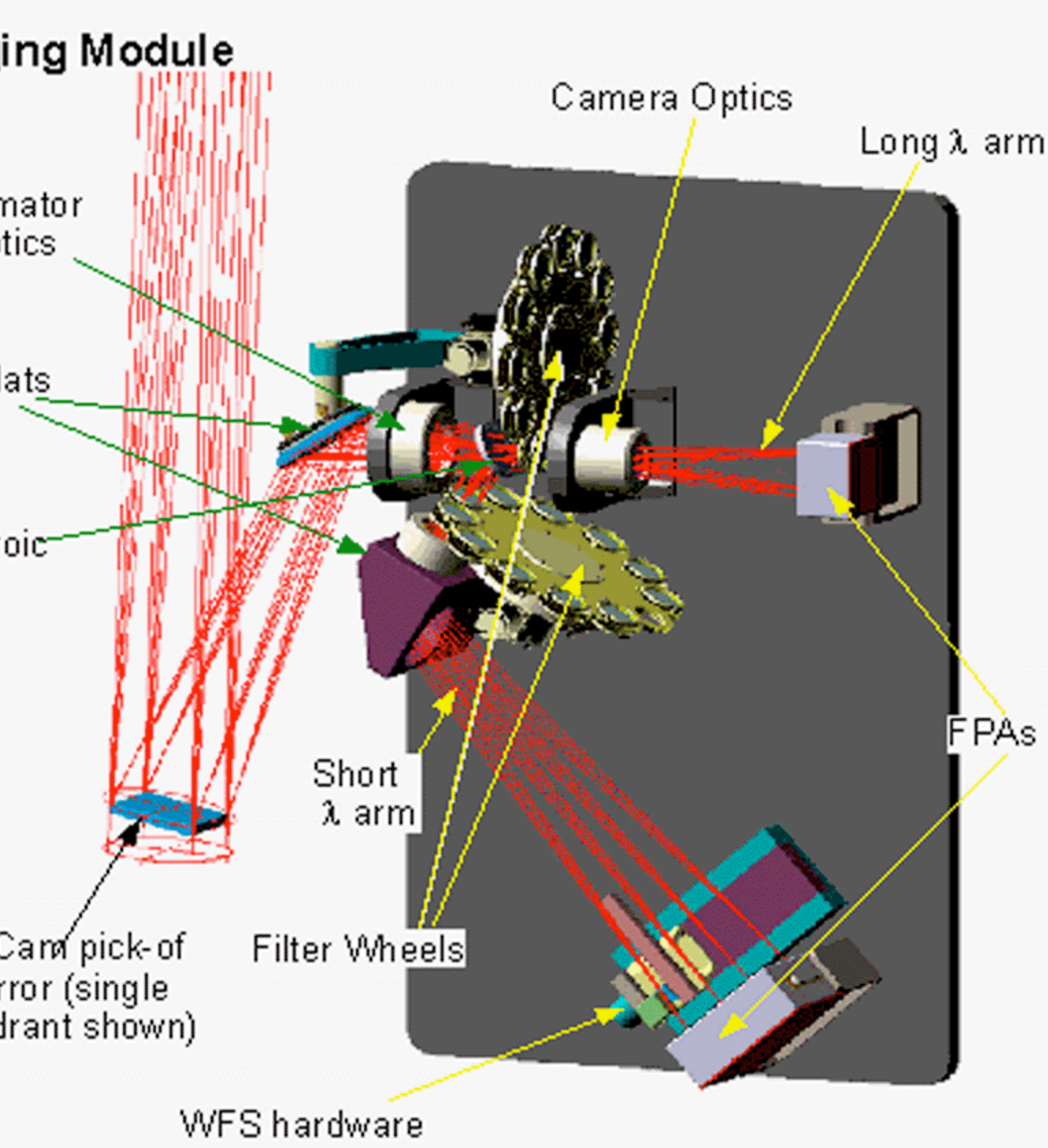
Observation	Instrument	Depth, Mode	Target
Ultra-deep survey (UDS)	NIRCam	1.4 nJy at 2 μm	10 arcmin^2
In-depth study	NIRSpec	23 nJy, $R \sim 100$	Galaxies in UDS area
	MIRI	23 nJy at 5.6 μm	Galaxies in UDS area
Lyman α forest diagnostics	NIRSpec	2×10^{-19} erg cm^{-2} s^{-1}, $R \sim 1000$	Bright $z > 7$ quasar or galaxy
Survey for Lyman α sources	TFI	2×10^{-19} erg cm^{-2} s^{-1}, $R \sim 100$	4 arcmin^2 containing known high-z object
Transition in Lyman α/Balmer	NIRSpec	2×10^{-19} erg cm^{-2} s^{-1}, $R \sim 1000$	UDS or wider survey area
Measure ionizing continuum	NIRSpec	2×10^{-19} erg cm^{-2} s^{-1}, $R \sim 1000$	Same data as above
Ionization source nature	NIRSpec	2×10^{-19} erg cm^{-2} s^{-1}, $R \sim 1000$	Same data as above
	MIRI	23 nJy at 5.6 μm	
LF of dwarf galaxies	NIRCam	1.4 nJy at 2 μm	UDS data

Assembly of Galaxies

TABLE III

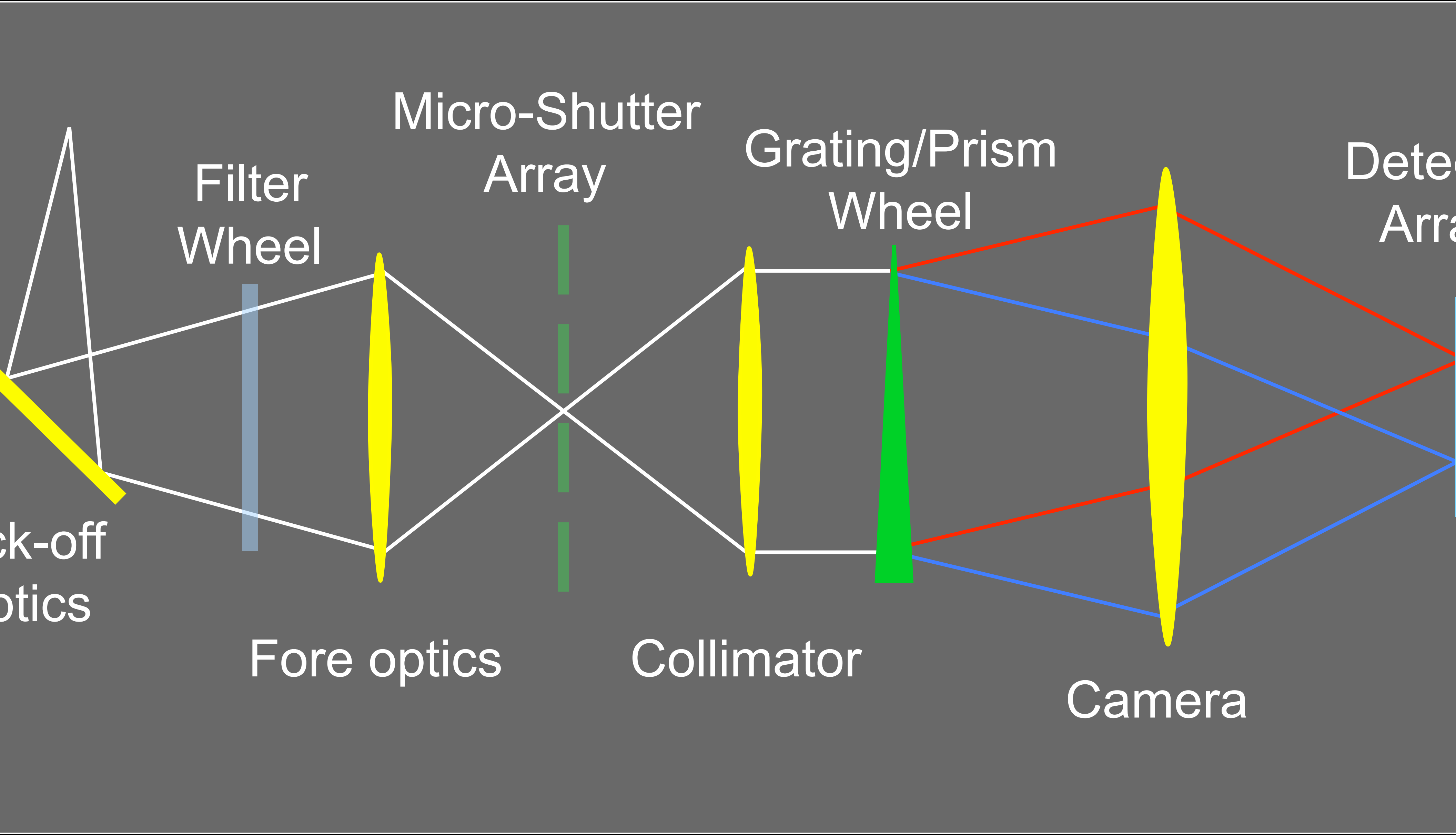
JWST measurements for the assembly of galaxies theme

bservation	Instrument	Depth, Mode	Target
eep-wide survey (DWS)	NIRCam	3 nJy at 3.5 μm	100 arcmin^2
etallicity determination	NIRSpec	5×10^{-19} erg s^{-1}cm^{-2}, $R\sim1000$	Galaxies in DWS
aling relations	MIRI	11 μJy at 9 μm, $R\sim3000$	Lyman Break galaxi at $z\sim3$
	NIRCam	3 nJy at 3.5 μm	DWS data
bscured galaxies	MIRI	23 nJy at 5.6 μm	ULIRGs
	NIRSpec	5×10^{-19} erg s^{-1} cm^{-2}, $R\sim1000$	ULIRGs and AGN
	MIRI	1.4×10^{-16} erg s^{-1}cm^{-2} at 24μm, $R\sim2000$	ULIRGs and AGN

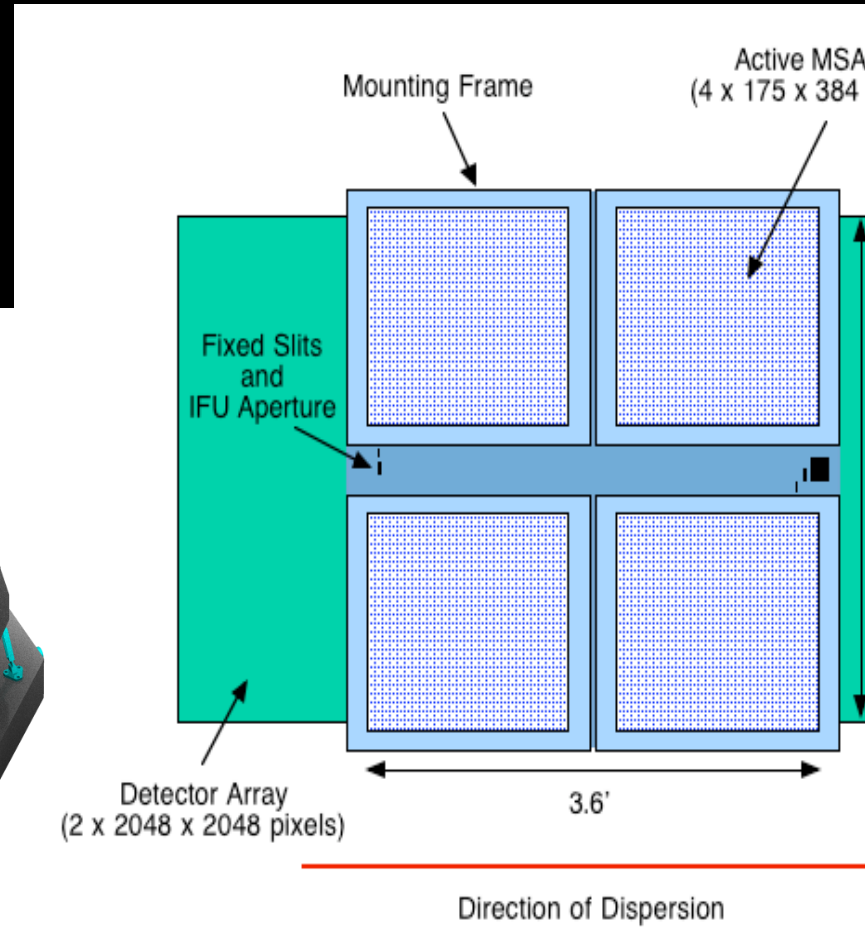


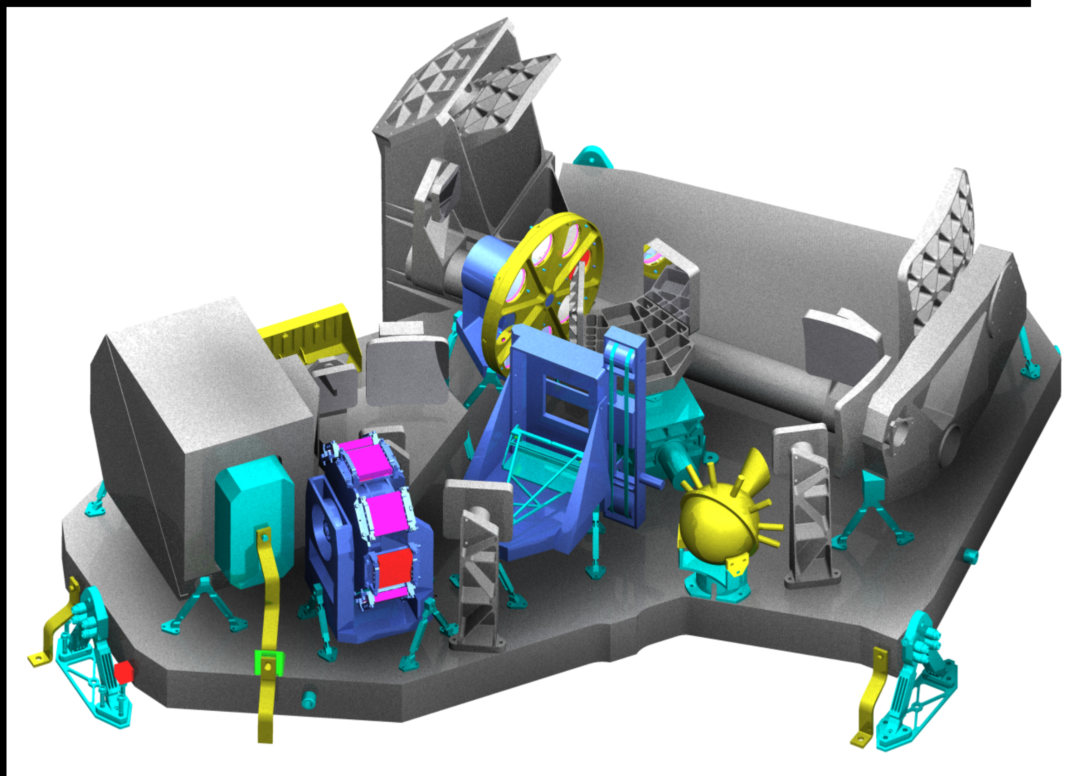
ing Module
Camera Optics
Long λ arm
mator
tics
lats
oic
FPAs
Short
λ arm
Cam pick-of
rror (single
drant shown)
Filter Wheels
WFS hardware

NIRSpec Schematic

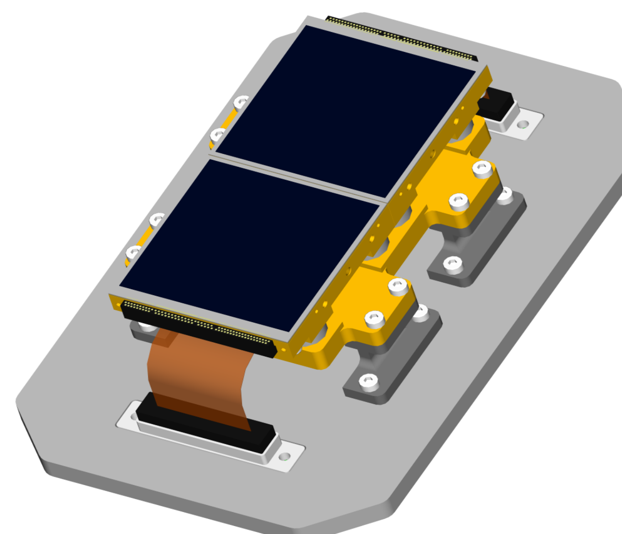


- > 100 Objects Simultaneously
- 9 square arcminute FOV





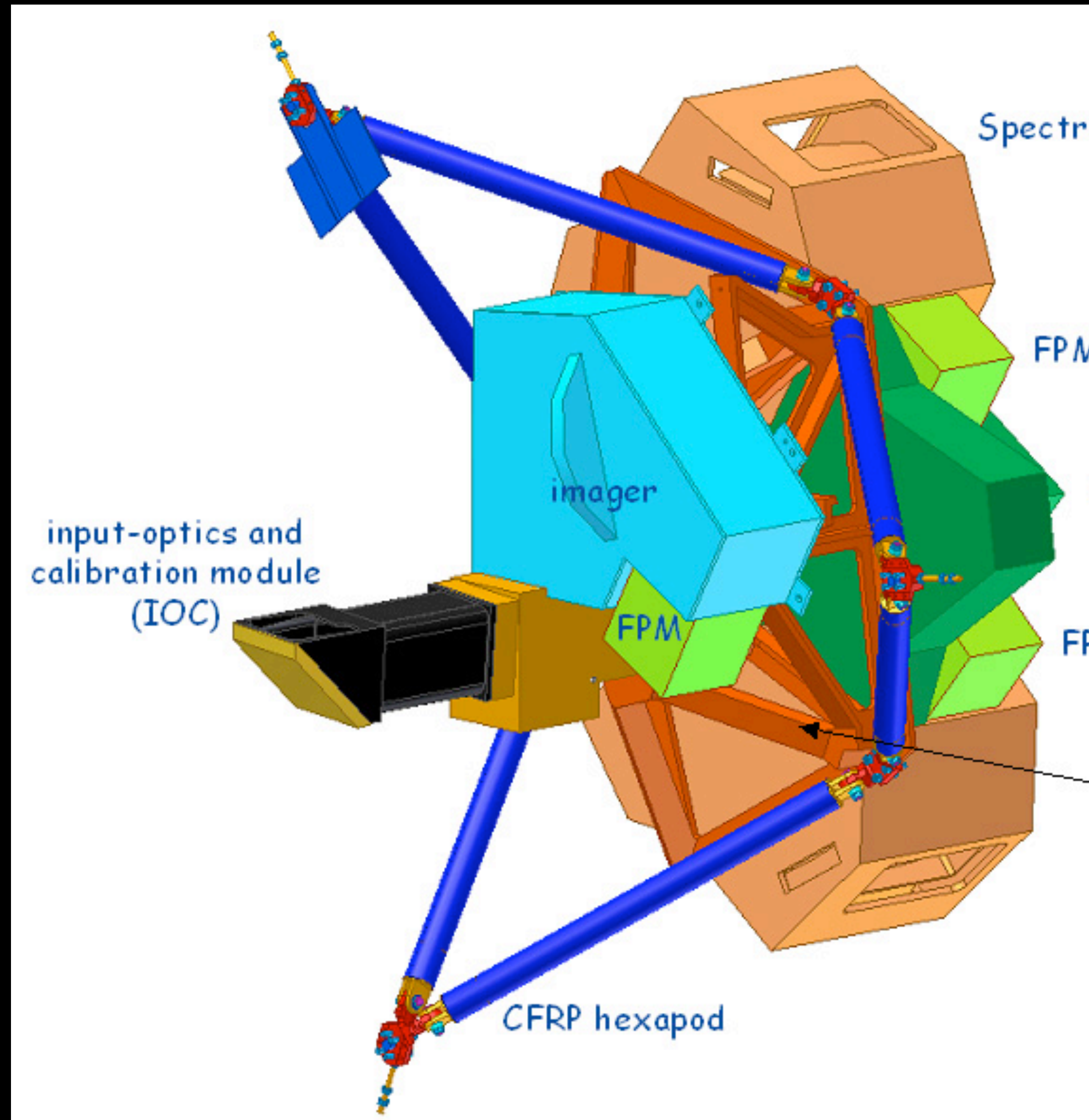
- **Implementation:**
  - 3.5' Large FOV Imaging Spectrograph
  - 4 x 175 x 384 element Micro-Shutter Array
  - 2 x 2k x 2k Detector Array
  - Fixed slits and IFU for backup, contrast
  - SiC optical bench & optics



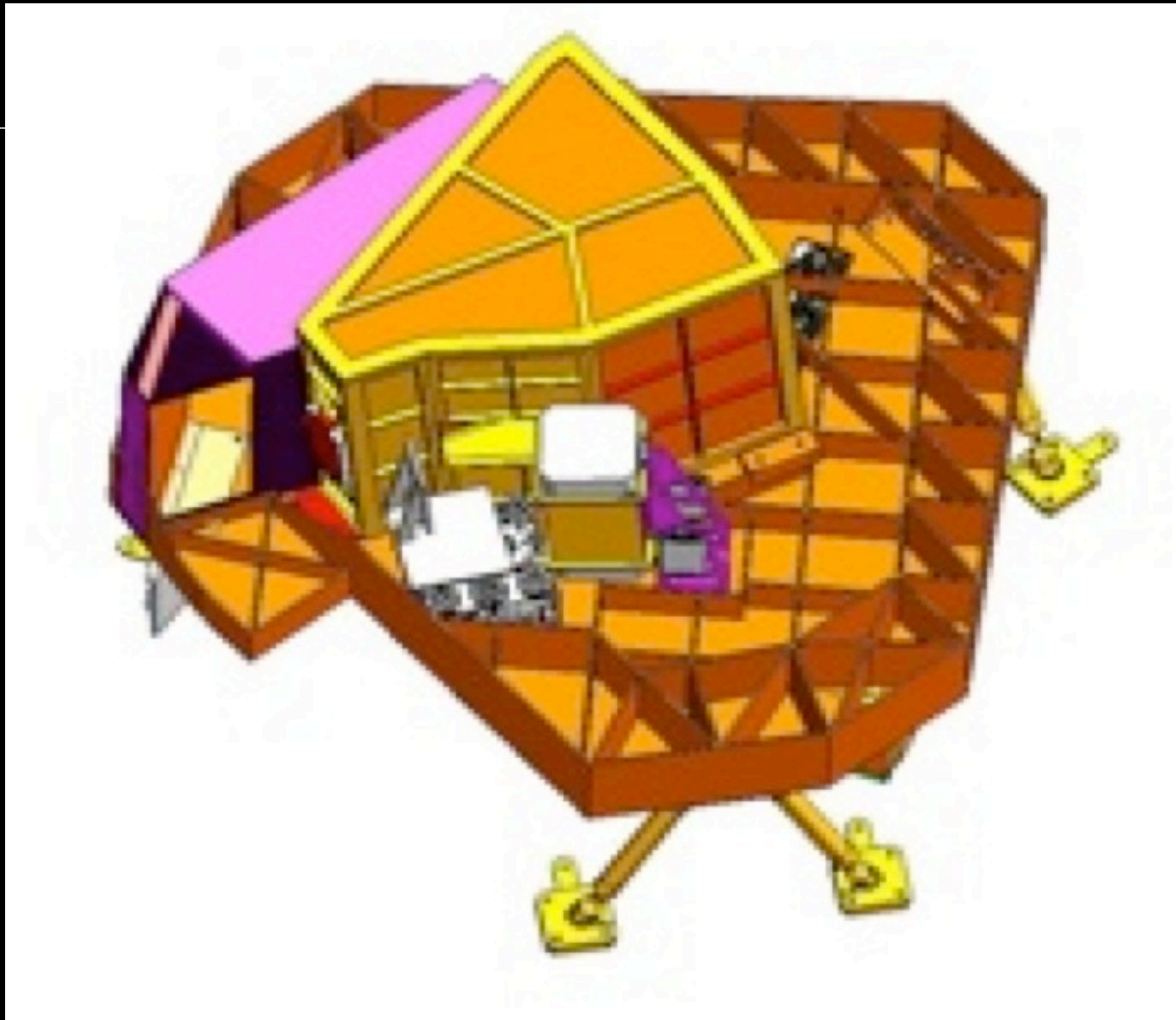
ence team G. Rieke (lead), G.Wright
lead)
opean Consortium sponsored by ESA
artnership with NASA/JPL
ence Goals include
- Search for the origins of galaxies
- Birth of stars and planets
- Evolution of planetary systems

ging
- λ=5-29 μm wavelength range
- Diffraction limited imaging with 0.1” pixels
- ~1.7’ field of view
- Able to image sources as bright as 4 mJy at λ=10μm
- ≥12 bandpass filters
- Low resolution spectrograph (R~100; λ=5-10 μm) for single, compact sources
- Simple coronagraph

ctroscopy
- λ=5-29 μm wavelength range, reach λ= 28.3 μm
- Integral field spectroscopy with > 3” field of view
- R~2000-3700 from λ=5-29 μm



Optics Module concept
developed by European Conso



- Guide star availability with >95% probability at any point in the
- Wide open bandpass for guiding (0.5 μm - 5.0 μm)
- Includes Tunable Filter Imager with R = 70 - 150, 1.7 μm - 4.
- Coronagraph

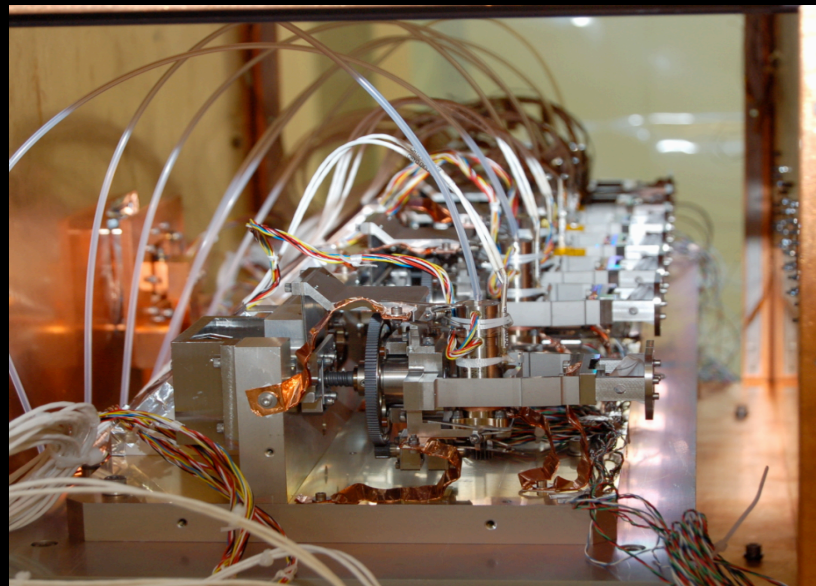
- General
  - JWST successfully completed Non-Advocate Review and Confirmation Review and is approved to begin Implementation Phase
  - All observatory components, except for the spacecraft and membrane management system of the sunshield, have successfully completed the preliminary design reviews
  - All science instruments successfully completed critical design reviews
  - HQ approved moving object tracking requirement
- Telescope and Mirrors
  - All flight primary, secondary and tertiary mirrors completed machining a are in stages of rough polishing, smooth out and figure grinding
  - Mirror “Manufacturing Percentage” progressed from 41% to 55%
- Observatory
  - Sunshield Preliminary Design Review held in February 2008
  - Observatory Integration & Test control room opened at NGST
- Ground Segment
  - Delivered all Science Instrument Integrated Test Sets (SITSs) and Science Instrument Development Units (SIDUs) to SI teams in the US, Canada and Europe

ntegrated Science Instrument Module (ISIM

- MIRI
  - MIRI Verification Model (VM) completed, tested and achieved 6.2K opera temperature and first light!
  - Selected flight detectors for MIRI
- NIRSpec
  - Delivered Engineering Test Unit detector subsystem to Astrium
  - Selection of flight detectors agreed to by NASA & ESA
  - ESA approved larger (1.6 arcsec square) aperture for NIRSpec for transi
- NIRCam
  - Selected ALL flight detectors and filters for NIRCam
  - Completed bonding and vibration testing of the NIRCam ETU Optical Be
- FGS
  - Held FGS System CDR at COM DEV
  - Engineering Test Unit assembly begun, tunable filter etalon tested at cryo
  - CSA added Non-Redundant Masking to their Tunable Filter Imager
- Structure
  - Completed bonding 5 of 13 Flight Hardware Decks

ch Restraint Flexures

od Mounting Brackets

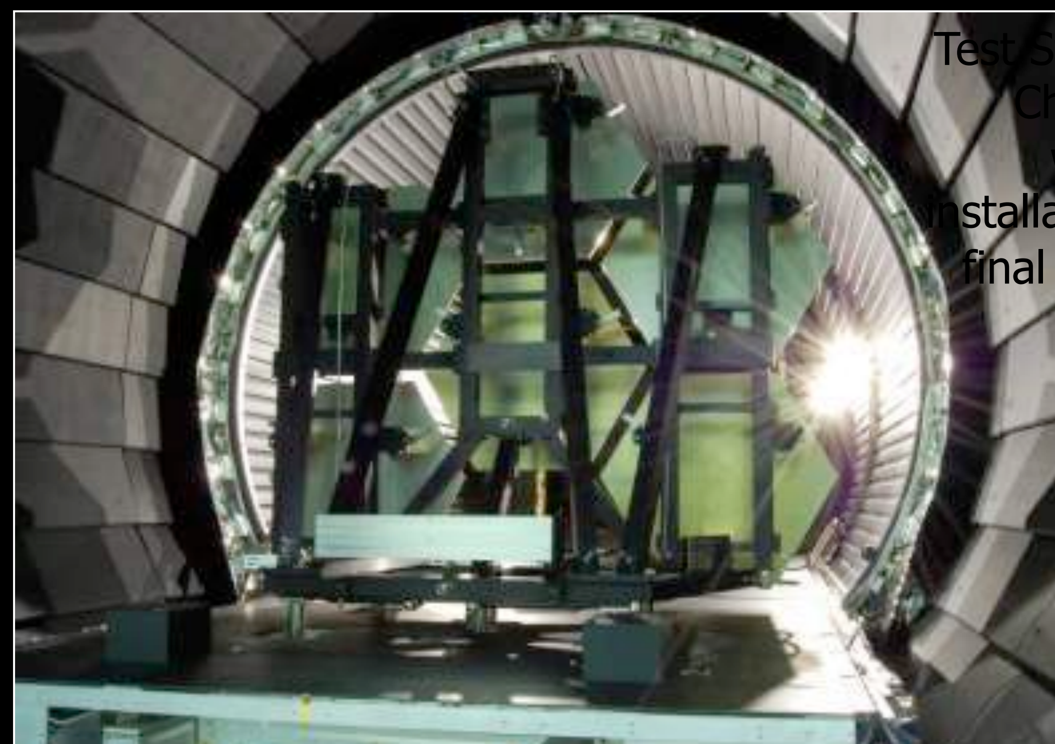


Flight actuators under test

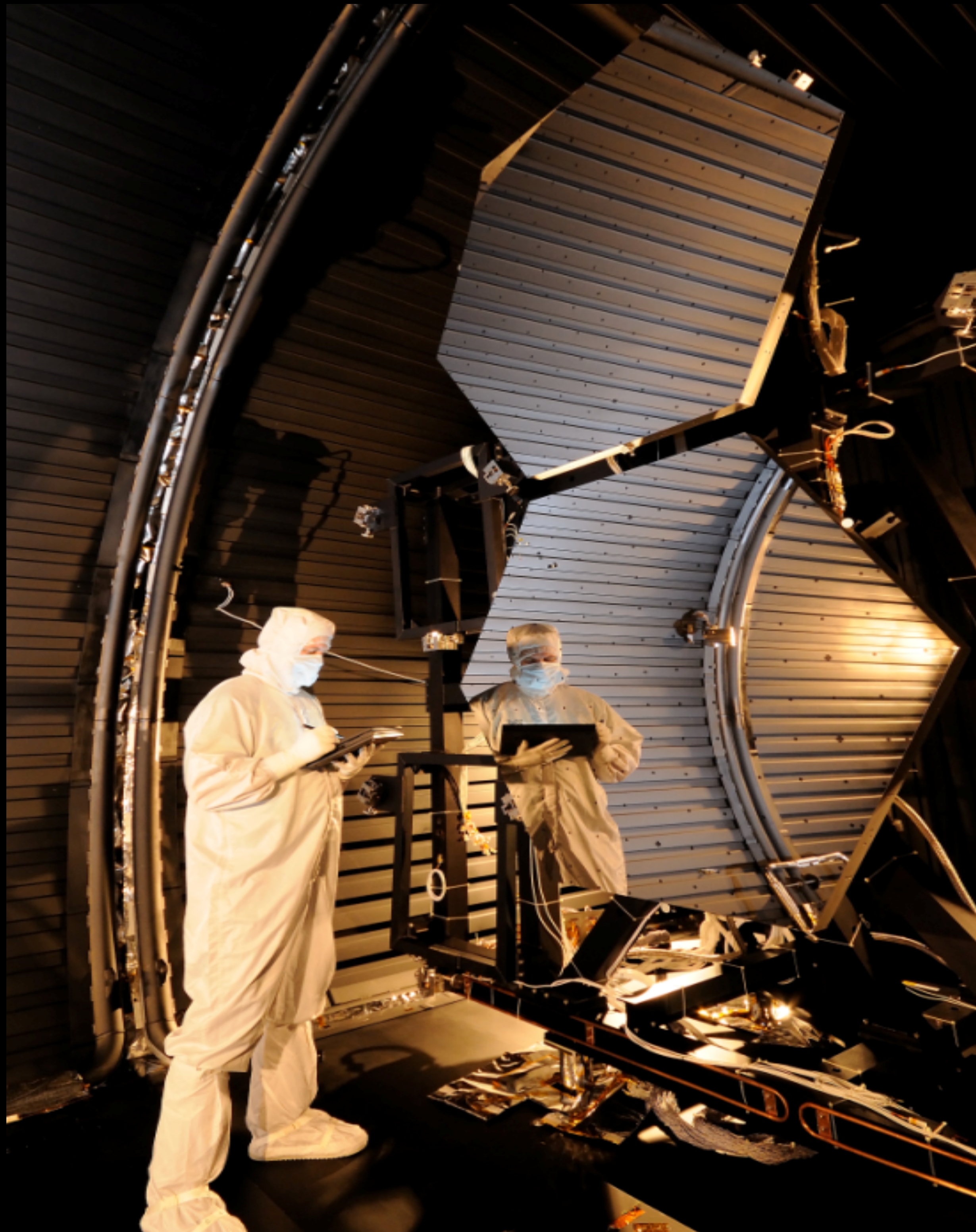
Test Stand on Flowtron waiting Integration into Chamber

Craning Test Sta in Pla

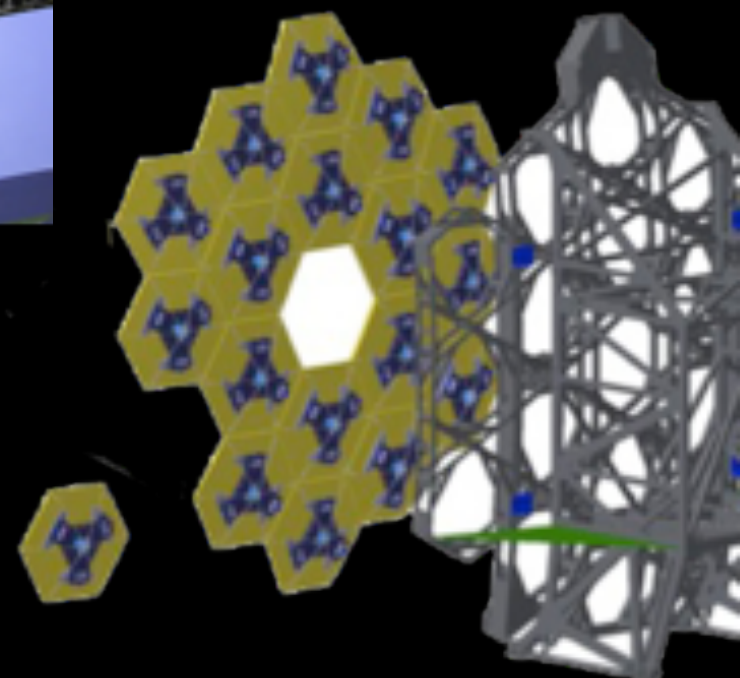
Installing Test Stand into Chamber

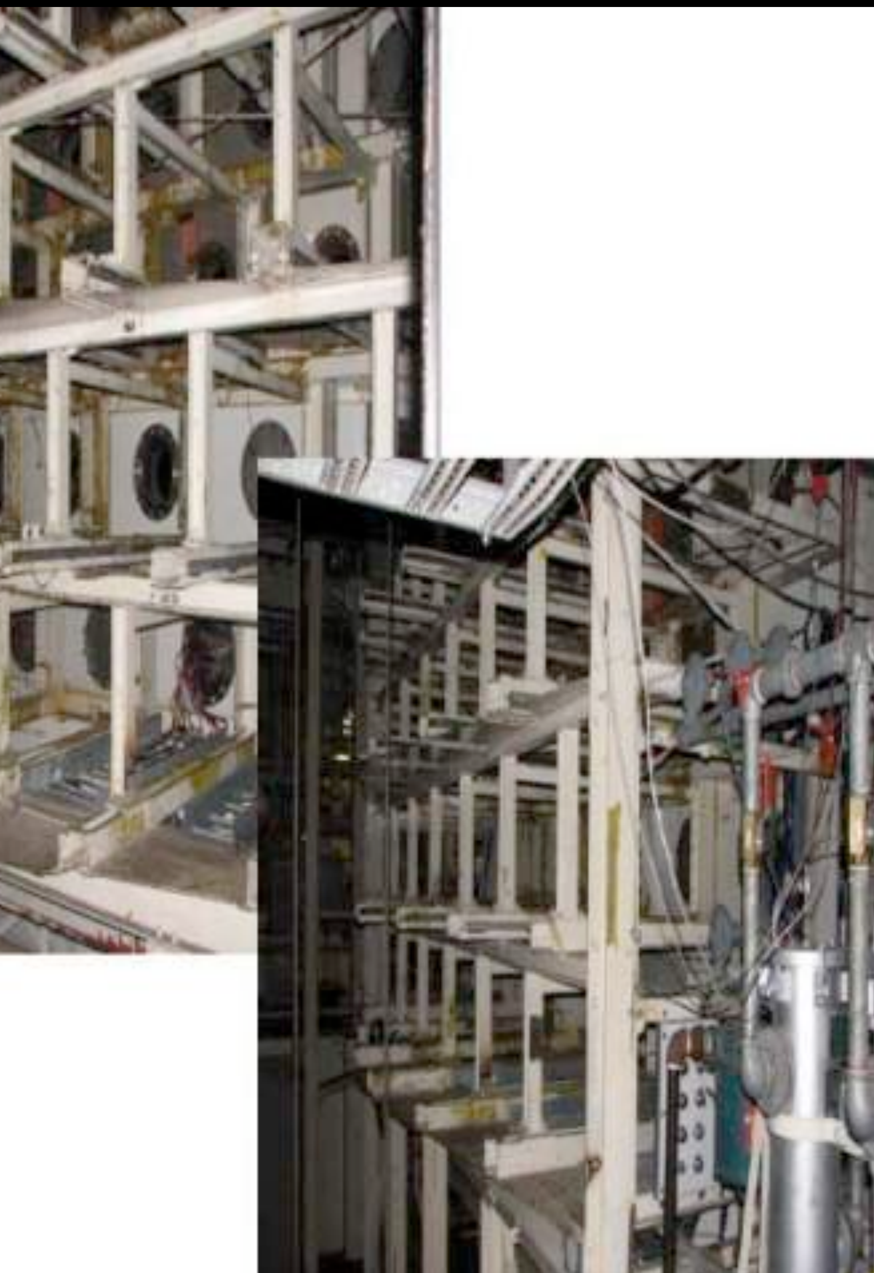


Test S Ch nstalla final

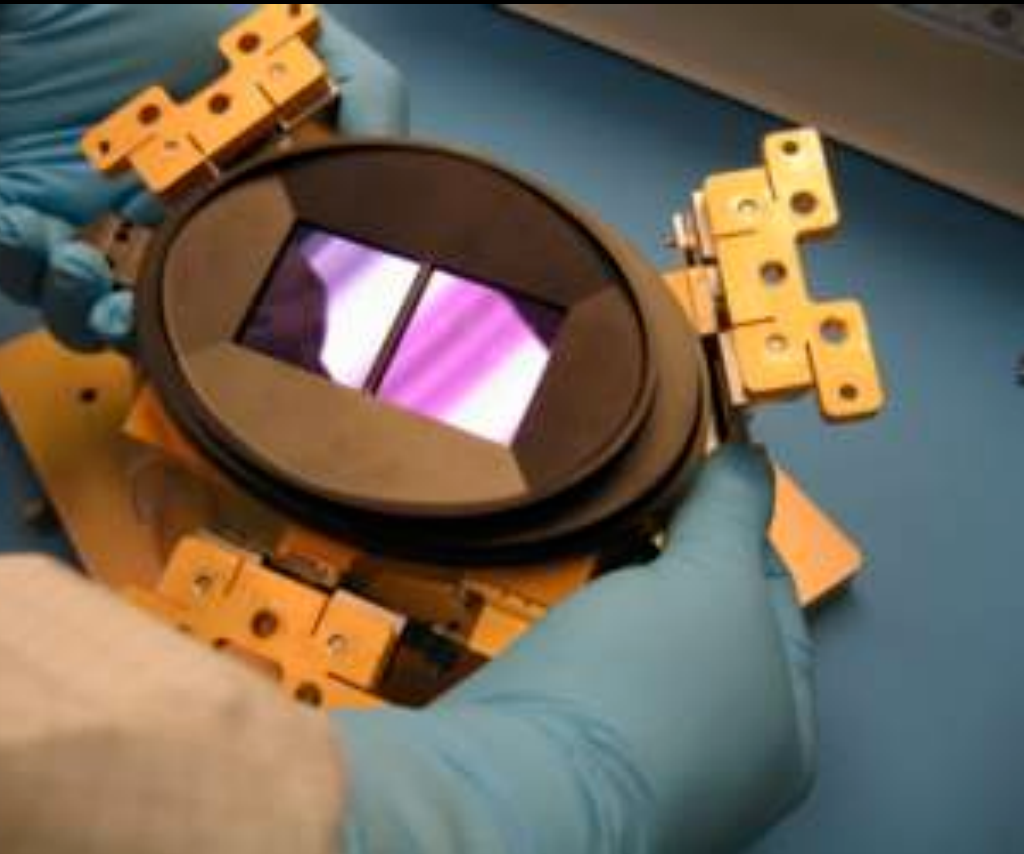


Flight Backplane Started





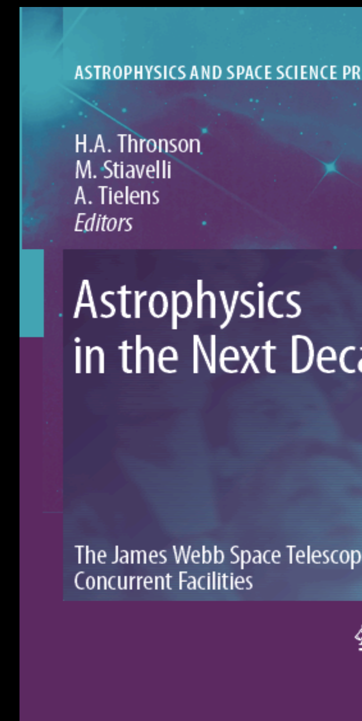
ternal chamber modifications – removal of solar simulator structures



NIRSpec Focal Plane Assembly

NIRCam Pupil Imaging Lens Mechanism

Sunshield Membrane Management System Preliminary Design Review, February
ISIM Critical Design Review, March
Assembly & Testing of NIRCam Engineering Test Unit, June
Observatory Flight Software Build 1 Critical Design, June
Microshutter device delivered from GSFC to NIRSpec, June
NIRCam Flight Instrument build commences, August
Electro-optical tests of ETU FGS at operating conditions, October
Mission Critical Design Review scheduled for December
MIRI Flight Instrument testing commences



2007 Tucson co
proceedings o

JWST Project seeking Associate Project Scientist for Integration ar
See AAS job bulletin position 25420

The James Webb Space Telescope Capabilities for Astrobiology

ark Clampin
VST Observatory Project Scientist
oddard Space Flight Center

ontributors: Jonathan Lunine, George Rieke, Don Lindler (GSFC), iza Miller-Ricci (CfA), Sara Seager (MIT), Tom Greene (NASA/ mes), Drake Deming (GSFC), and JWST SWG and SI Teams

The NASA Astrobiology Roadmap

- Goal 1 — Understand the nature and distribution of habitable environments in the universe. Determine the potential for habitable planets beyond the Solar System, and characterize those that are observable.

- GOAL 7 — Determine how to recognize signatures of life on other worlds and on early Earth. Identify biosignatures that can reveal and characterize past or present life in ancient samples from Earth, extraterrestrial samples measured in situ or returned to Earth, and remotely measured planetary atmospheres and surfaces. Identify biosignatures of distant technologies.

Documentation

- Astrobiology Whitepaper: Lunine & Seager
    - (Google “jwst white paper”)
- JWST Coronography Whitepaper
- JWST Transit Science Whitepaper
- Space Science Reviews

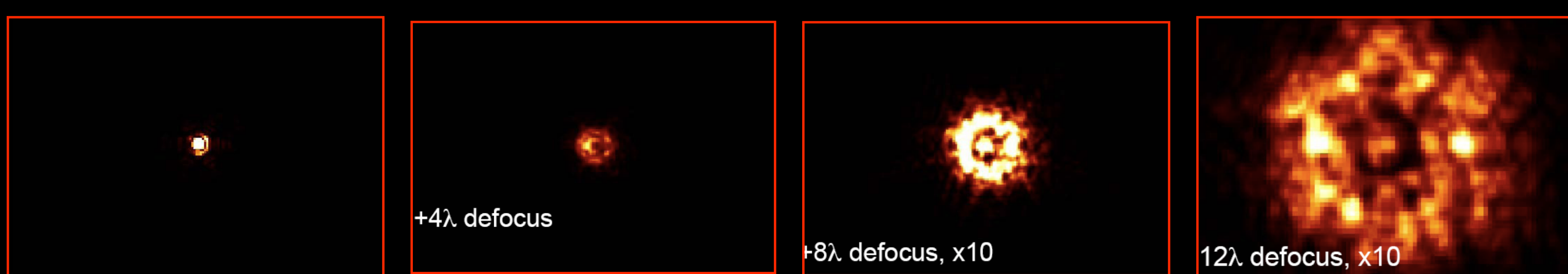
Astrobiology Themes

- High contrast imaging and spectroscopy of Brown Dwarfs and Extrasolar Giant Planets
- Formation of planetary systems: tracing evolution of planetary systems from dust clouds to debris disks
- Studies of water and prebiotic organics in comets;
- Characterize organic and inorganic matter needed to create habitable environments
- Characterization of exoplanets via transit imaging

λ (μm)	Spectral Resolution (λ/δλ)	FOV	Mode	Comments	Application
- 2.3 - 5.0	4, 10, 100 4, 10, 100	2 x (2.2' x 2.2') 2 x (2.2' x 2.2')	Imaging Imaging	Photometric Imaging	High precision light curves of trans photometry of point source images coverage permits photometric mon primary or secondary eclipses.
– 2.3	4, 10, 100	2 x (2.2' x 2.2')	Phase diversity imaging	Defocusing of images to 57 or 114 pixel diameters	High precision light curves of trans with bright objects which need to b avoid saturation within the minimur time
– 5.0	2000	2 x (2.2' x 2.2')	Long-λ Grism	Backup capability for WFSC. Used with F277W, F322W, F356W, F410M or F444W	Emission spectroscopy of hot gas g planets
) – 5.0	100, 1000, 2700	0.1" x 2.0", 0.2" x 3.5", 0.4"x 4.0"	Spectroscopy	Fixed long slits	Low and intermediate resolution tra emission spectroscopy of transiting
7 - 5.0	2700	3" x 3"	Spectroscopy	Integral Field Unit	Intermediate resolution, transmissi emission spectroscopy of transiting
– 29	4-6	1.9' x 1.4'	Imaging	Photometric Imaging	
- 11	100	5" x 0.2"	Spectroscopy	Fixed Slit or Slitless	Light curves of transits from photor source images.
) – 7.7 – 11.8 – 18.2 – 28.8	3000 3000 3000 3000	3.7" x 3.7" 4.7" x 4.5" 6.2"x 6.1" 7.1"x7.7"	Spectroscopy	Integral field unit	Intermediate resolution, emission s transiting planets.
– 2.5	100	2.2' x 2.2'	Imaging	Selectable central λ	High precision light curves of trans photometry of point source images coverage permits photometric mon primary eclipses.
? – 4.9	100	2.2' x 2.2'	Imaging	Selectable central λ	High precision light curves of trans photometry of point source images

NIRCam Team Transit Science

- R~1700 over entire LW channel, λ = 3 - 5 μm simultaneously (but limited by filters in series)
- No slit losses w/good sampling (0.065” vs NIRSpec 0.1”)
  - Precise transit spectrophotometry
  - Especially important for eclipse mapping
- Defocused imaging for transit photometry
  - Sub-arrays available for defocused imaging
  - 4λ, 8λ, 12λ waves of defocus



NIRCam Performance

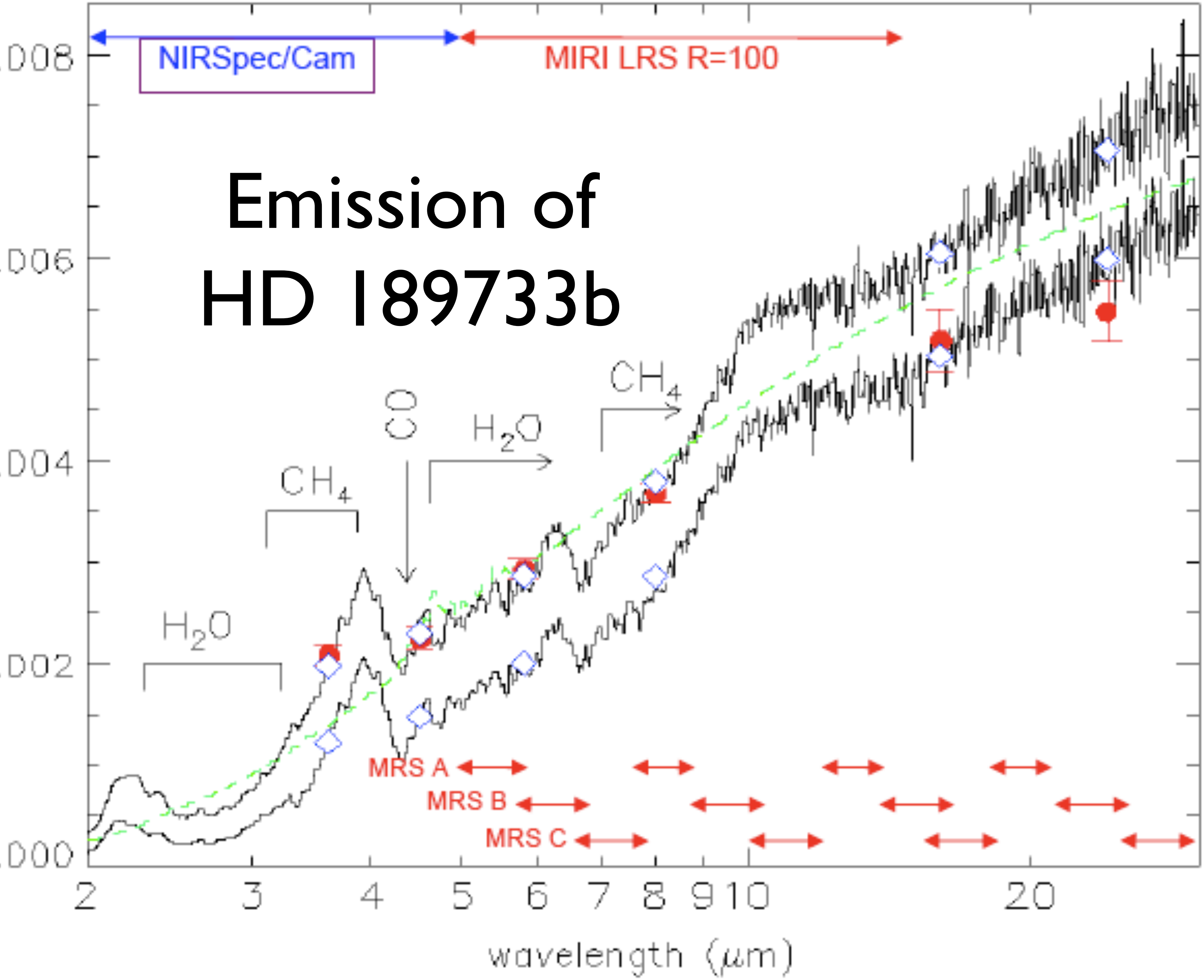
Secondary eclipses of a hot Jupiter around bright
G2V stars realistic to detect in R≤500 spectra.

Hot Earths cannot be detected around G2V stars
R=500 secondary eclipse spectra

High S/N R=500 spectra of a Jupiter around M2-
stars can be observed via secondary eclipse.

Secondary transits of Hot Earths around M5V sta
could be detected at low SNR in R~50 spectra in
~10^4 sec

NIRCam → MIRI



CH4, CO, H2
constrain
temperature
C abundanc

Red symbols
measuremen

Top curve ha
fluz absorbe
day side onl
bottom has
uniform ene
redistributio

Dashed line

Charbonnea
Knutson,
Barman, Alle
Mayor, Mege
Queloz, & U
(2008)

MIRI Team Science

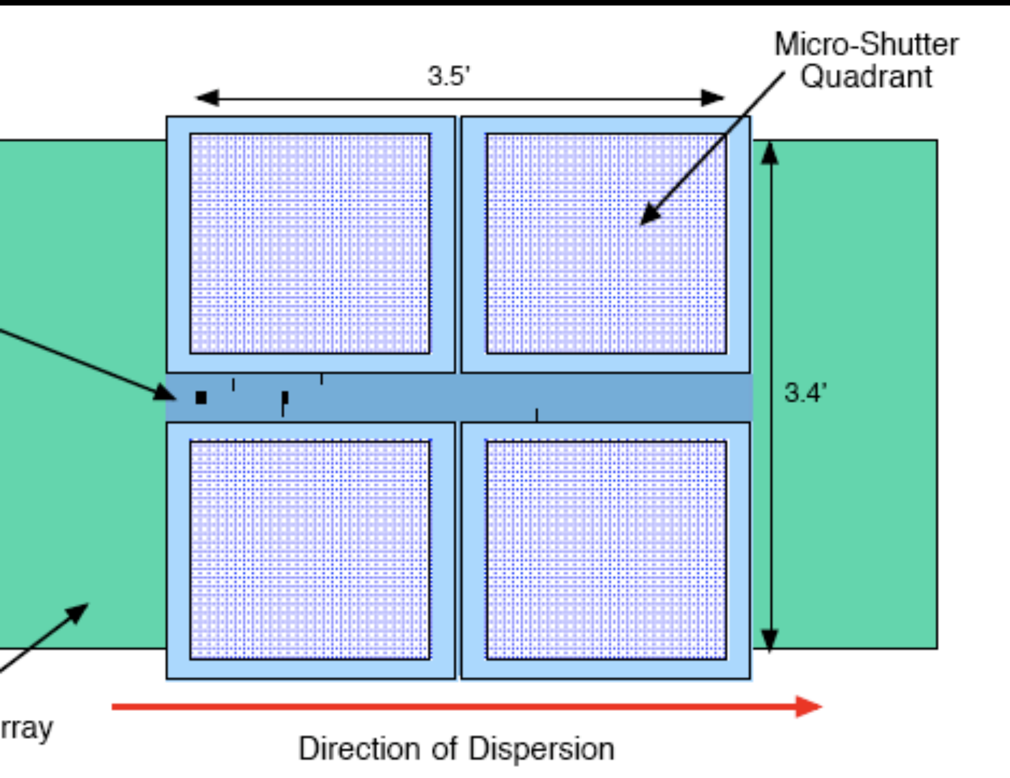
- Imager can observe bright sources with good sampling

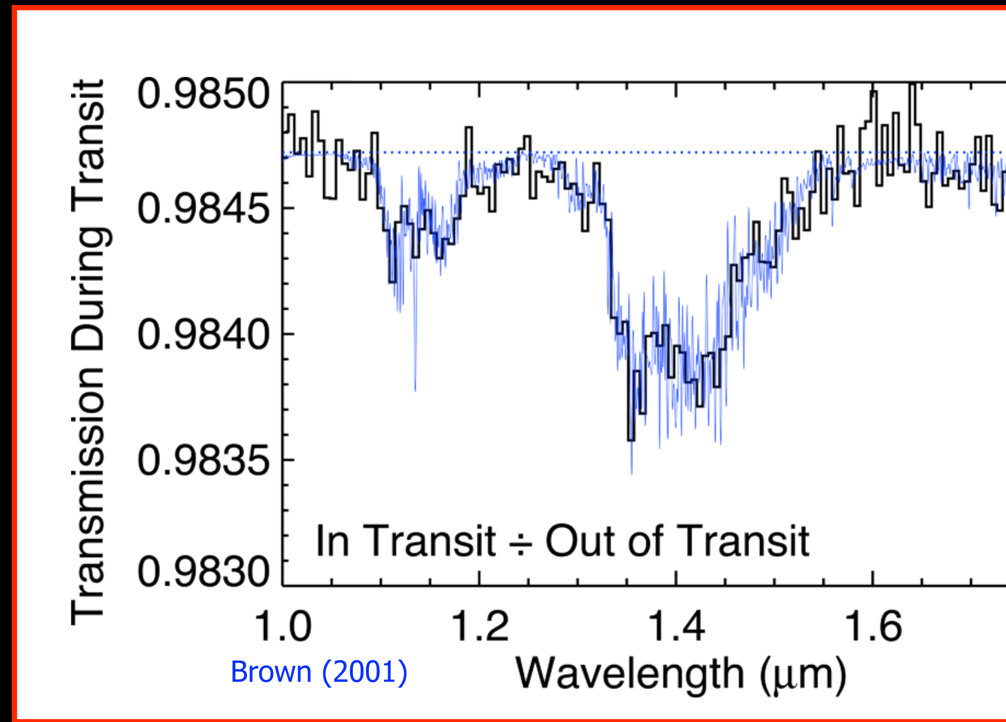
- MIRI imager should detect even small (1-2 $R_\oplus$) planets when transiting bright GKM stars

- LRS may be best to characterize the spectra of hot giant planets with high S/N and at R<=100 spectral resolution
  - Hot giant features detectable in a single transit @ R~50!

- MRS will be useful for R = 100 – 2000 spectra
  - 3 settings required to cover any broad spectral range

NIRSpec Team Science



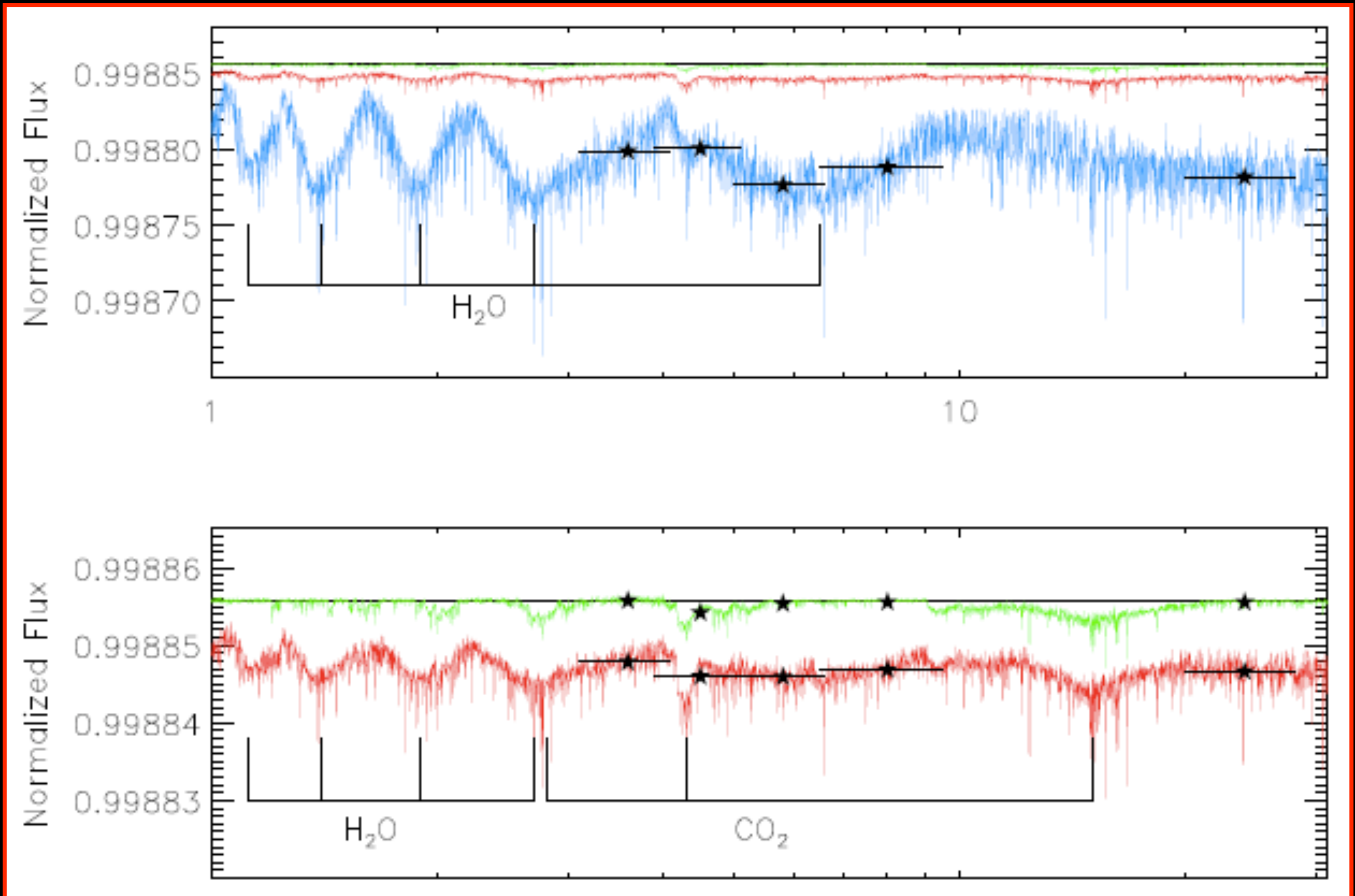


NIRSpec Transit Spectrum for HD 209458 at K

- pec designed for multi-object
- ntly added 1.6'x1.6" slit for
t spectroscopy
- sampled pixels remain a
rn wrt systematics

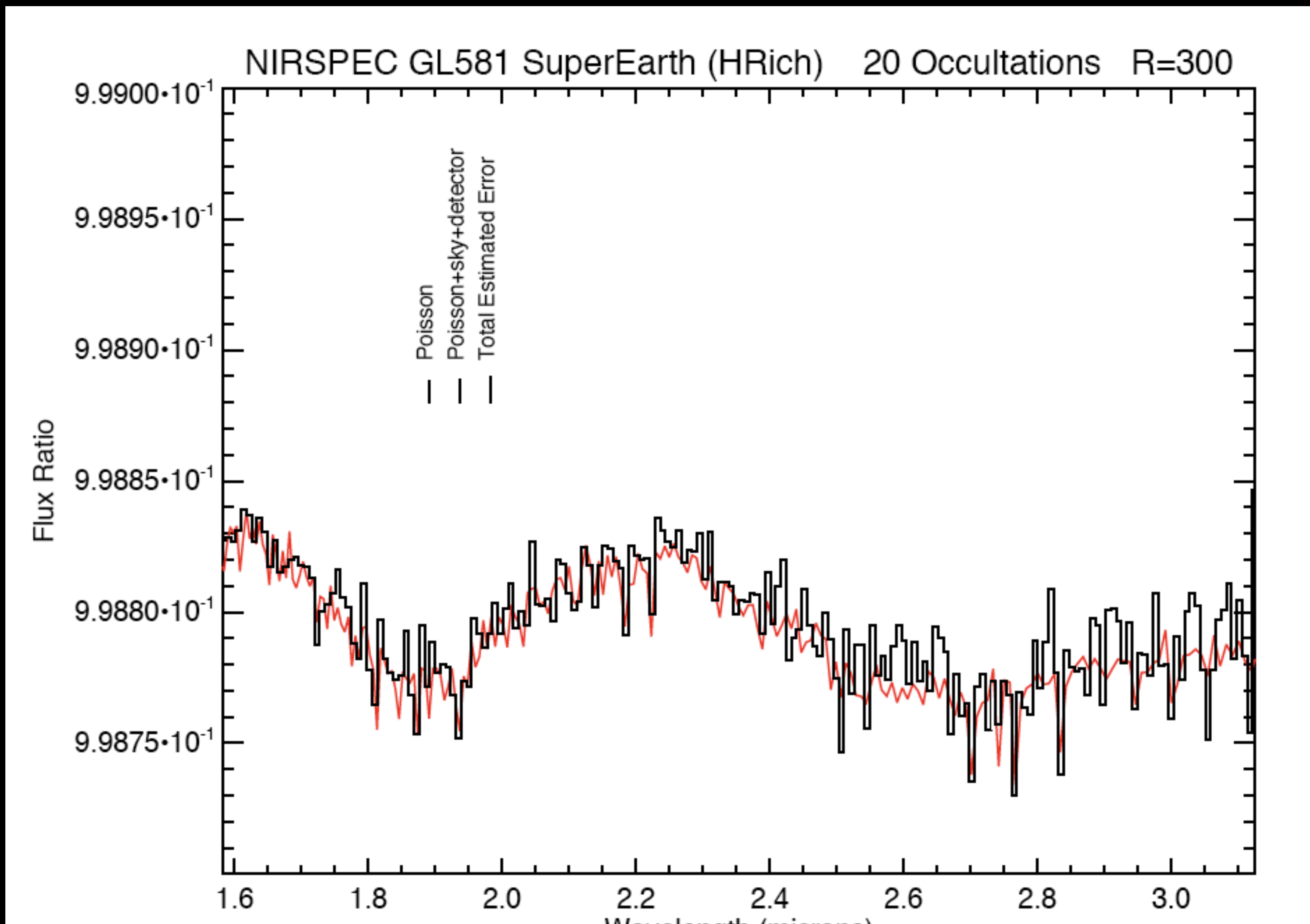
Model Spectra

- **The Atmospheric Signatures of Super-Earths: How to Distinguish Between Hydrogen-Rich and Hydrogen-Poor Atmospheres,** **Eliza Miller-Ricci, Sara Seager & Dimitar Sasselov,** [2008arXiv0808.1902M]



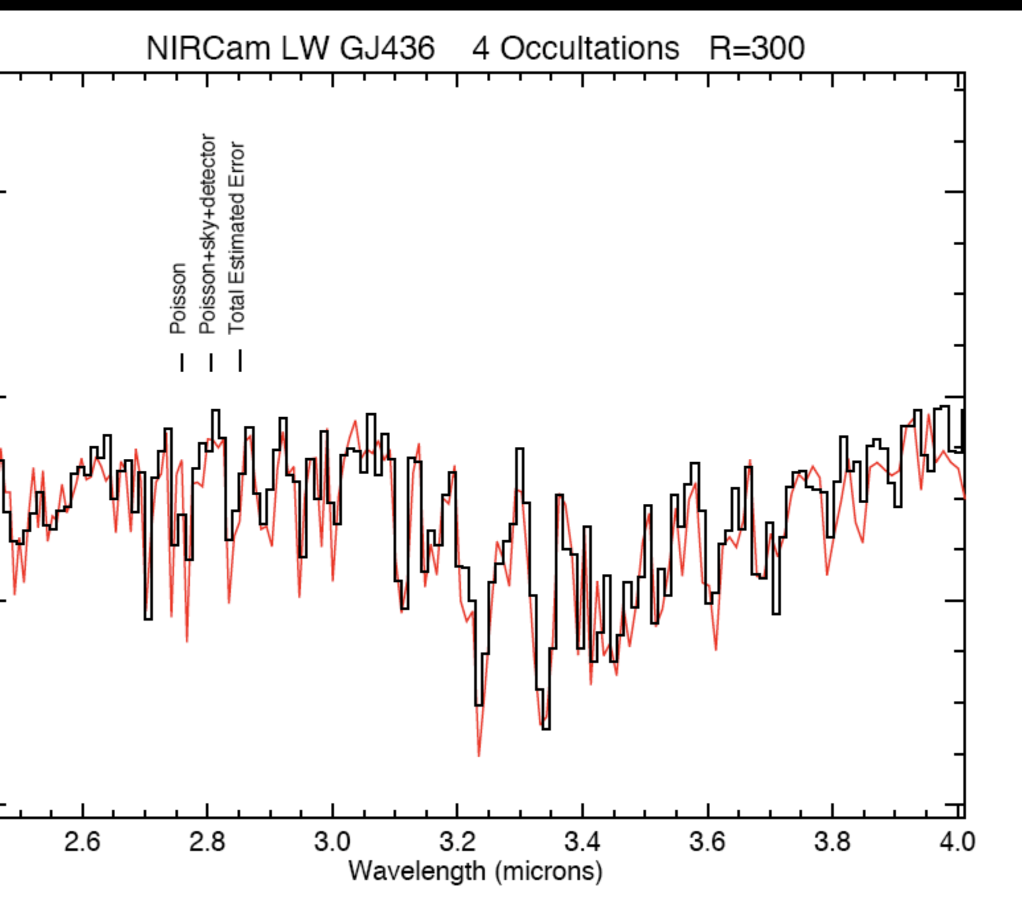
GL 581 - H_{rich} SuperEarth

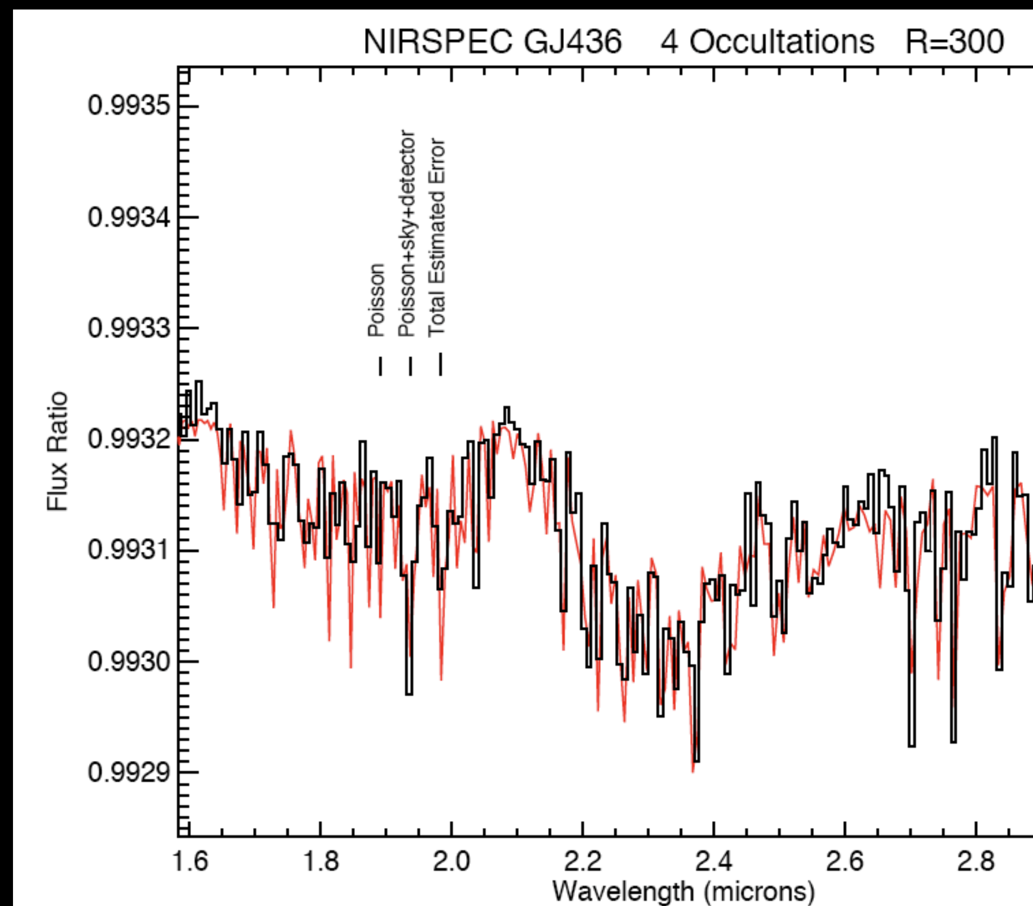
- NIRSpec - 20 transits
- Binned to R~300



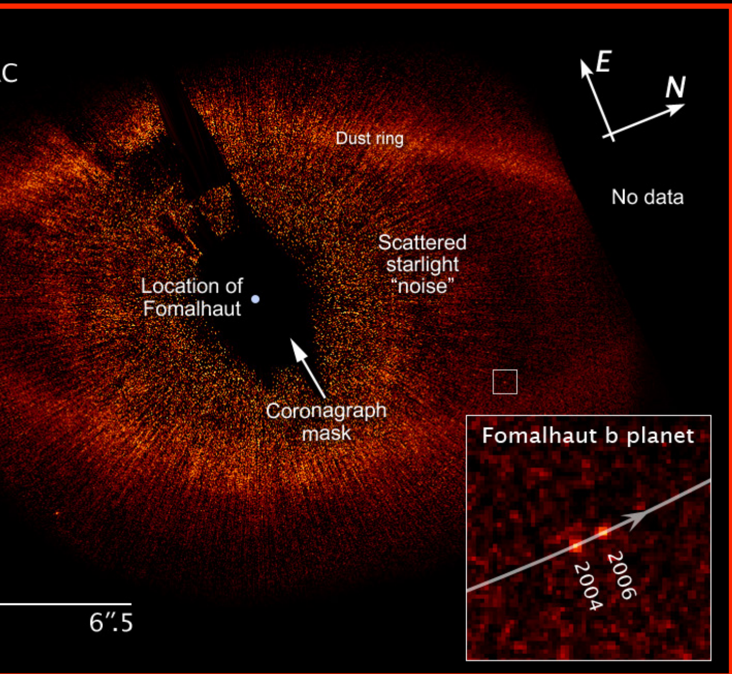
GJ436 _ Transmission

- **NIRSpec - 4 transits**
- **Binned to R~300**

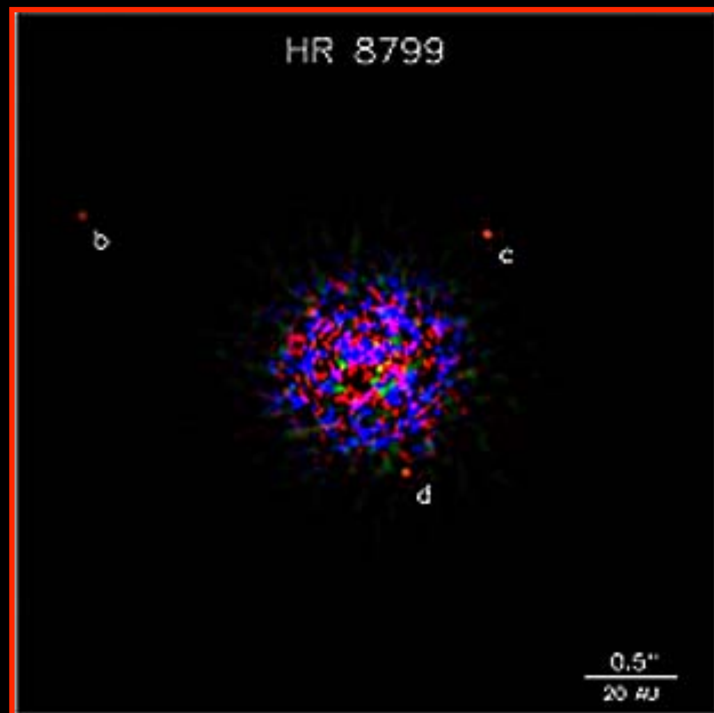




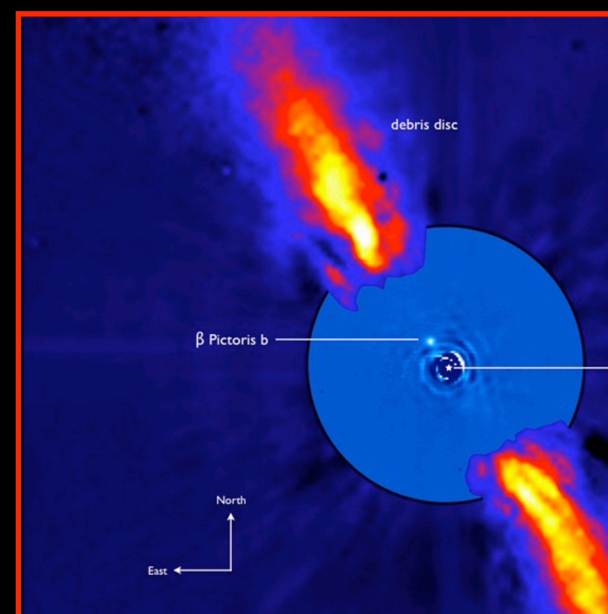
Crop of Recent Detections:



Fomalhaut B
Kalas et al. 2008



HR 8799
Marois et al. 2008



β Pic

Imaging/Spectroscopy Modes

ment	Channel/Mode	λ (μm)	R ($\lambda/\delta\lambda$)
n	Short λ Lyot Coronagraph	0.6 - 2.3	4, 10, 100
n	Long λ Lyot Corongagraph	2.4 - 5.0	4, 10, 100
	Multi-λ coronagraph	1.6 - 2.5	100
	Multi-λ coronagraph	3.2 - 4.9	100
	Non-redundant mask	1.6 - 2.5	100
	Non-redundant mask	3.2 - 4.9	100
	Quadrant Phase Coronagraph	10.65	20
	Quadrant Phase Coronagraph	11.4	20
	Quadrant Phase Coronagraph	15.5	20
	Lyot Coronagraph	23	5

High Contrast Imagi

	Integral field spectrograph	5.86 - 7.74	3000
	Integral field spectrograph	7.43 - 11.84	3000
	Integral field spectrograph	11.44 - 18.20	3000
	Integral field spectrograph	17.53 - 28.75	2250
ec	Integral field spectrograph	0.7 - 5.0	2700

Integral Field Spectr

Coronography (Dressler summary)

NIRCam coronagraph (Krist 2007; Greene et al 2006)

- Inner Working angle $\geq$ 4λ/D (500-750 mas at 3-5 μm)
- Outer Working Angle ±10”
- Dynamic range 10^5 (12.5mag) - 10^6 (15 mag) far from star

TFI/Non Redundant Mask (Sivaramakrishnan et al)

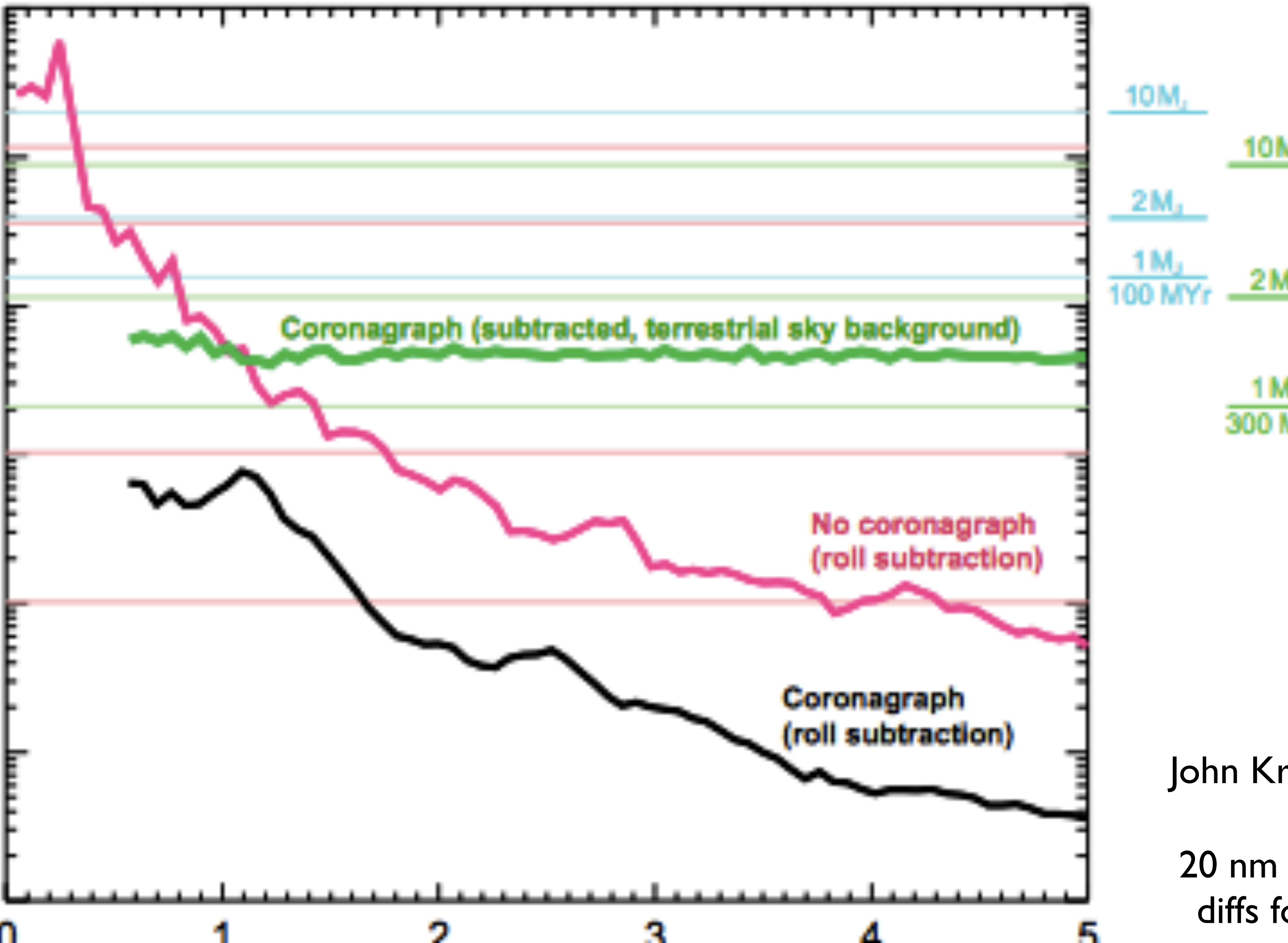
Inner Working angle ~ 0.5λ/D (75 mas at 5 μm)

Outer Working Angle 0.5”

Dynamic range 10^4 (10 mag) possibly up to 10^6 (12.5 mag) with careful calibration, flat fielding

- MIRI classic Lyot and 4-quadrant phase plate

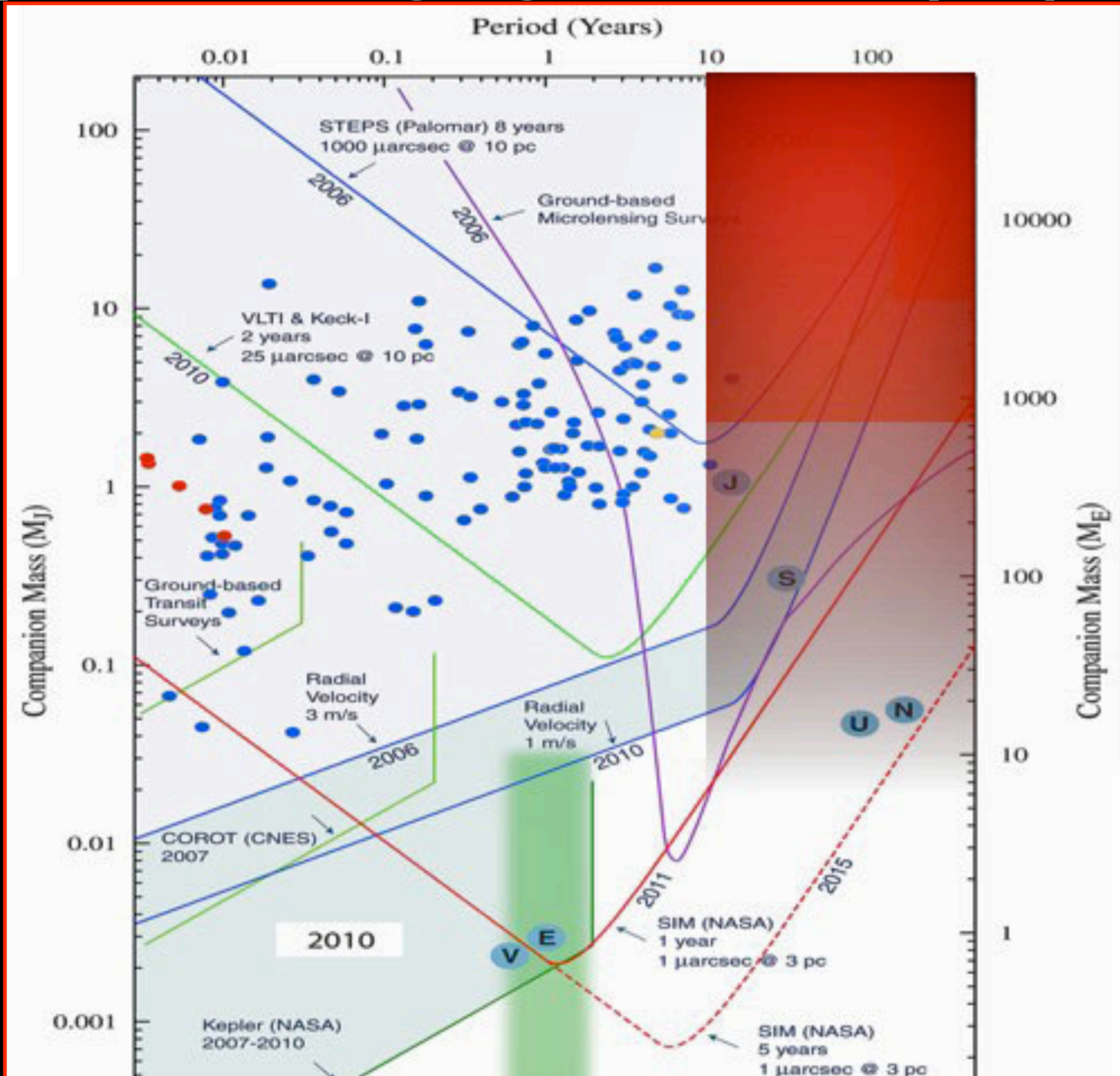
Mostly disks but also planets on distant orbits (Fomalhaut-b)



John Kr

20 nm
diffs fo

Exoplanet Imaging Discovery Space



Courte

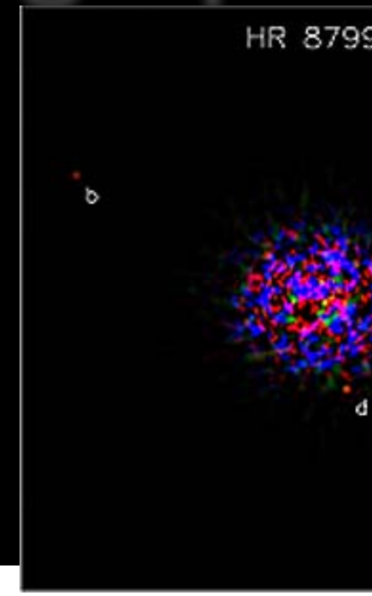
Tunable Filter Imager Coronagraph

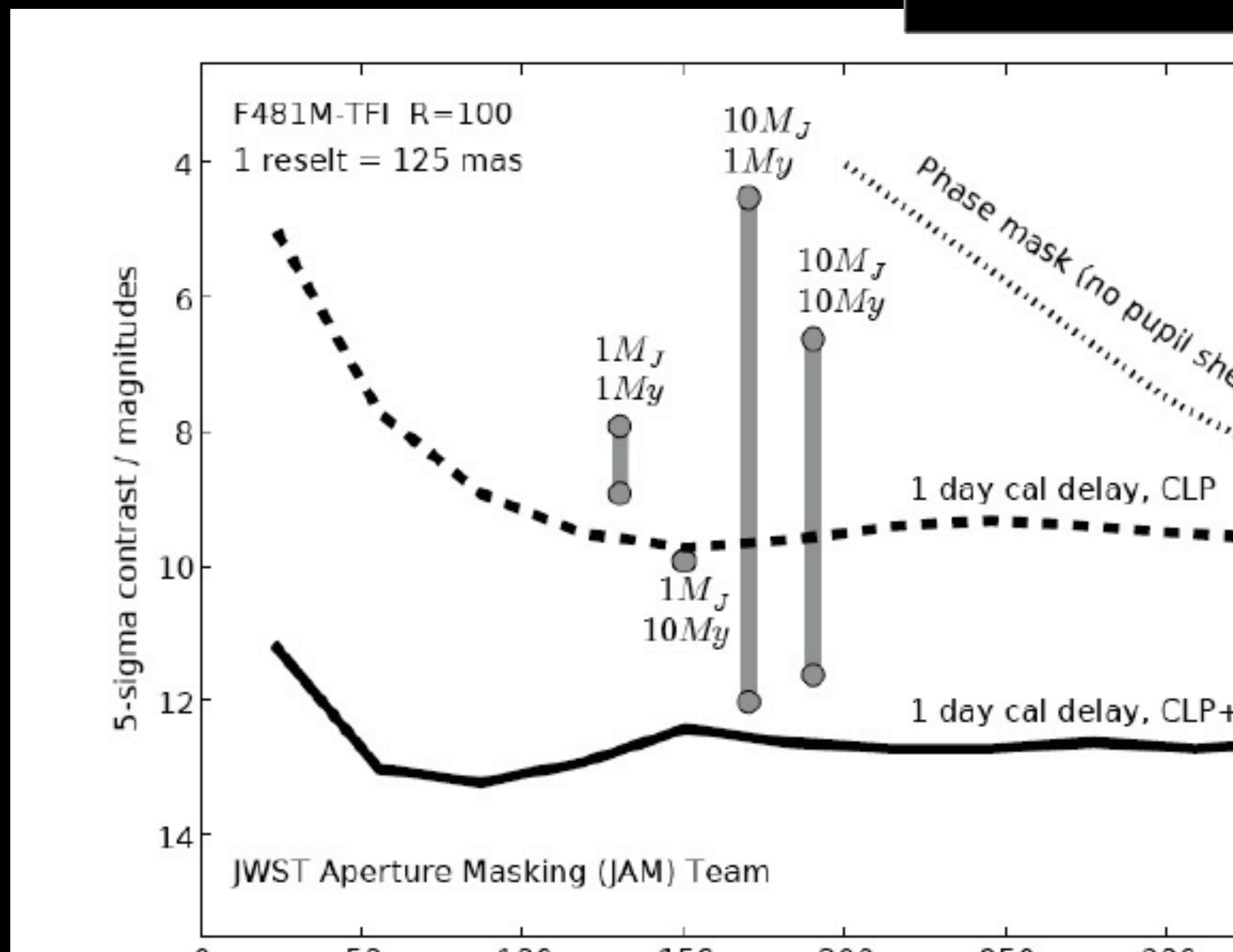
TFI Coronagraphic Capability Summary

- **Wavelength range:** 1.5-2.5, 3.1-5.0 μm
- **Field of view:** 20″x20″
- **Coronagraph**: Differential Speckle Imaging
- **Contrast** gain of ~10x versus NIRCam
- **Inner working angle: 4 λ/D**
- Technique employed on HR8799 (Marois et al. 2008)

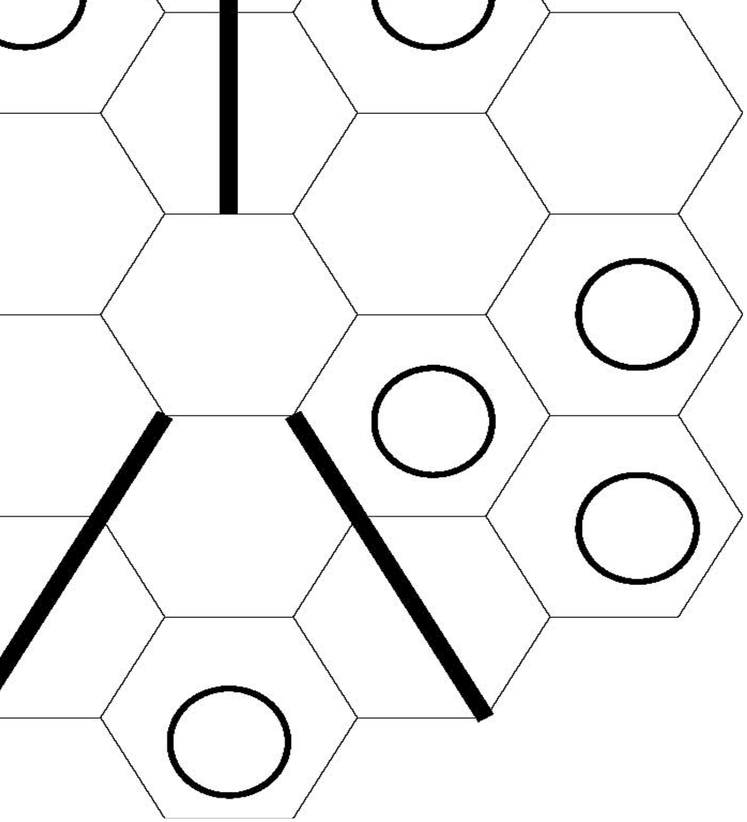
Non-redundant Mask

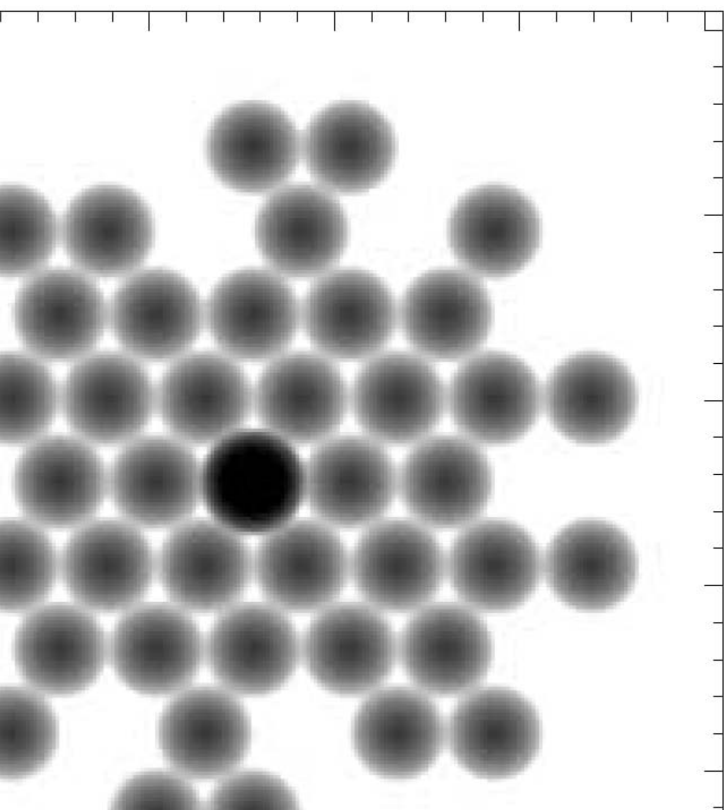
- **Wavelength range:** 1.5-2.5, 3.1-5.0 μm
- **Coronagraph**: Closure Phase Imaging
- **Trades inner working angle: 0.5 λ/D against contrast**





Imaging





- New mode for FGS/TFI utilizes “interferometric” mask producing 21 baselines and a narrow PSF (0.5λ/D
- Ground-based contrast limits ~5 mag space > 10 mag possible at small IW
- Flat fielding issues may be problem (>>Photon noise) for bright stars

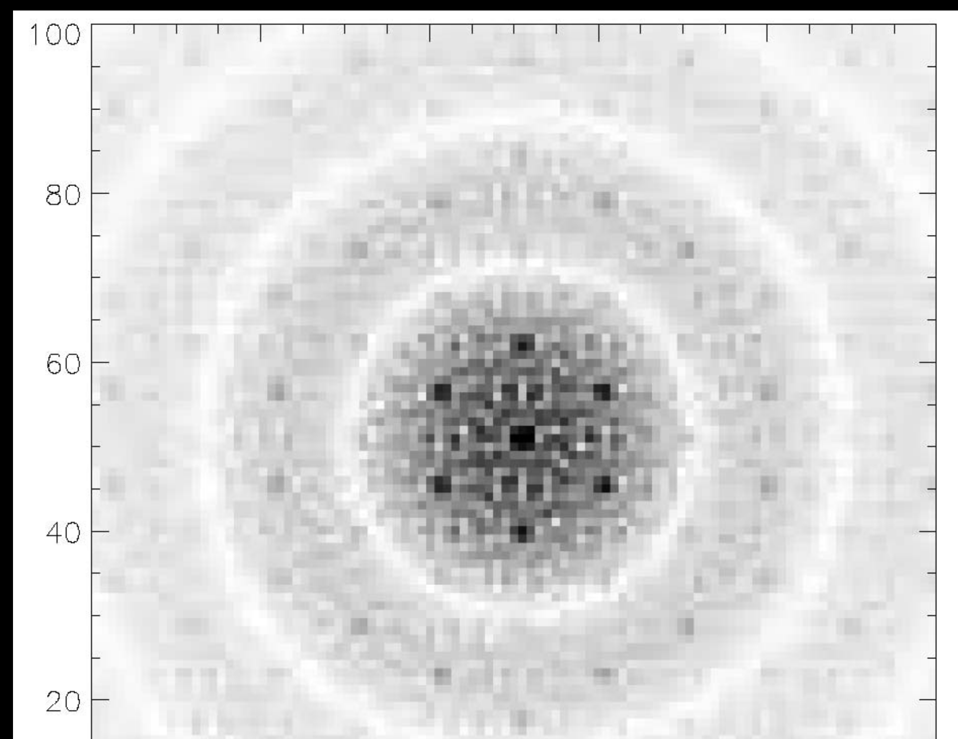


Table 1 – *Log₁₀* of planet/star contrast at 4.6 µm (TFI Coronagraph)[1]

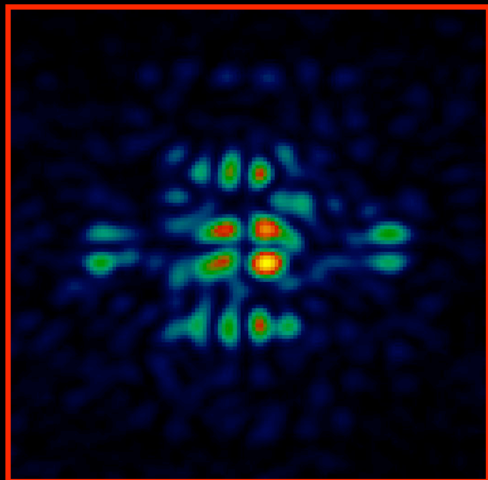
M_m	0.01 Gyrs			0.10 Gyrs			1 Gyrs			5 Gyrs	
	1 M_J	5 M_J	10 M_J	1 M_J	5 M_J	10 M_J	1 M_J	5 M_J	10 M_J	1 M_J	5 M_J
0.78	-5.09	-4.16	-3.78	-5.96	-4.94	-4.47	-7.67	-5.83	-5.33	-8.87	-6.95
2.27	-4.49	-3.56	-3.18	-5.37	-4.35	-3.88	-7.07	-5.24	-4.74	-8.27	-6.36
3.58	-3.97	-3.04	-2.66	-4.84	-3.82	-3.35	-6.55	-4.71	-4.21	-7.75	-5.83
4.29	-3.68	-2.76	-2.38	-4.56	-3.54	-3.07	-6.26	-4.43	-3.93	-7.46	-5.55
4.69	-3.52	-2.60	-2.22	-4.40	-3.38	-2.91	-6.10	-4.27	-3.77	-7.30	-5.39
5.15	-3.34	-2.41	-2.03	-4.22	-3.20	-2.72	-5.92	-4.08	-3.58	-7.12	-5.20
7.98	-2.21	-1.28	-0.9	-3.08	-2.06	-1.59	-4.79	-2.95	-2.45	-5.99	-4.07
10.15	-1.34	-0.41	-0.03	-2.22	-1.20	-0.72	-3.92	-2.08	-1.58	-5.12	-3.22
10.98	-1.01	-0.08	0.30	-1.88	-0.86	-0.39	-3.59	-1.75	-1.25	-4.79	-2.88
11.40	-0.84	0.09	0.48	-1.72	-0.70	-0.22	-3.42	-1.58	-1.08	-4.62	-2.70
12.38	-0.45	0.48	0.86	-1.33	-0.31	0.16	-3.03	-1.20	-0.70	-4.23	-2.31

Contrast exceeds the 10σ sensitivity beyond 1". [2]
Contrast exceeds the 10σ sensitivity beyond 5". [2]
Contrast exceeds the 10σ sensitivity beyond 1" *without* coronagraph and no PSF calibration.

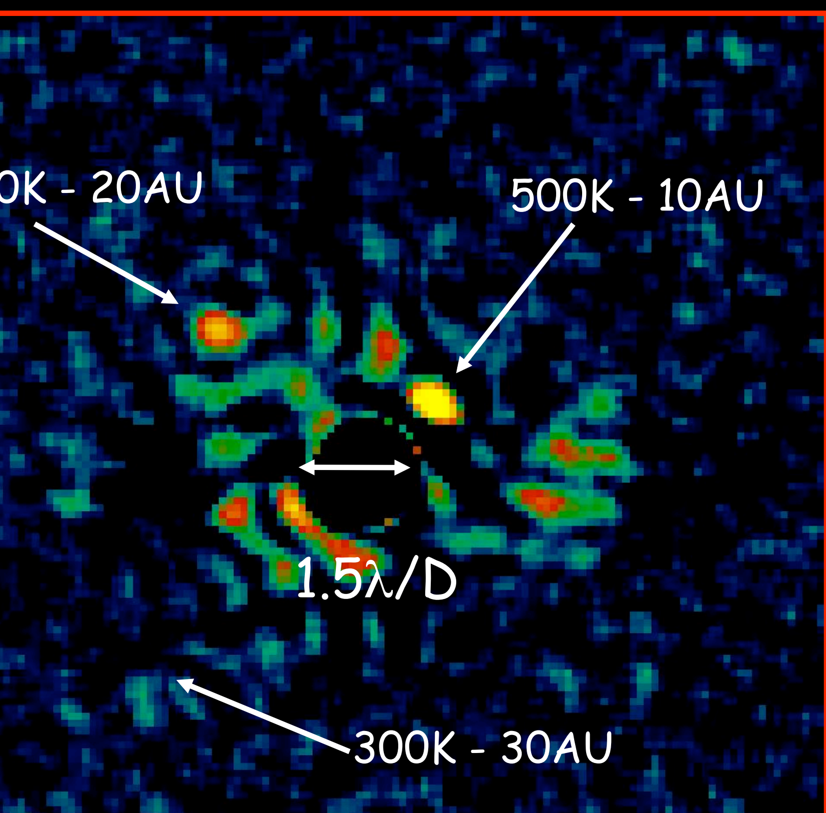
lutionary models from Barraffe *et al* 2003.
trast threshold assuming the 2" (FWHM) occulting spot and a speckle noise attenuation factor ~

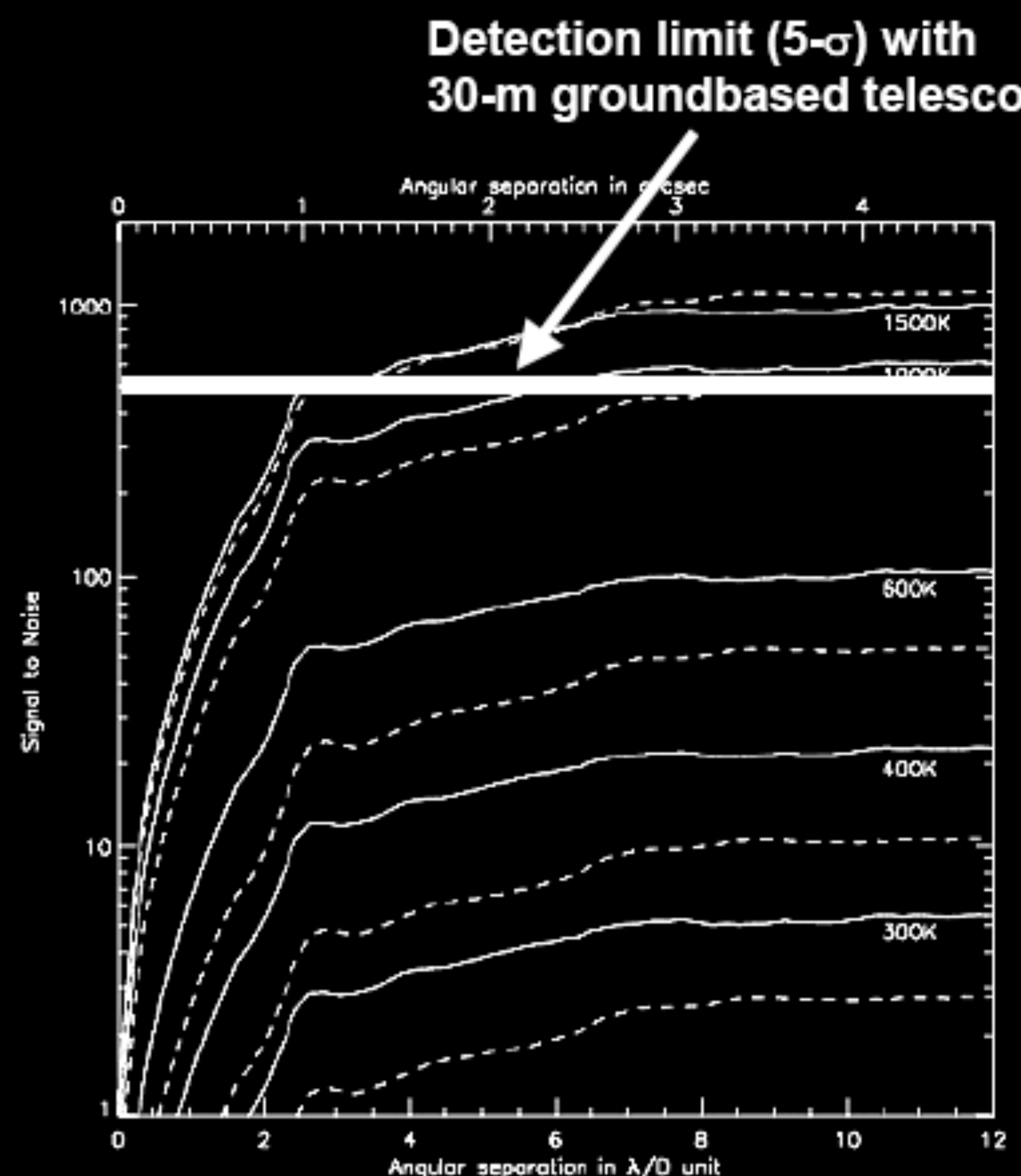
MIRI Exoplanet Detection Limits

i et al.



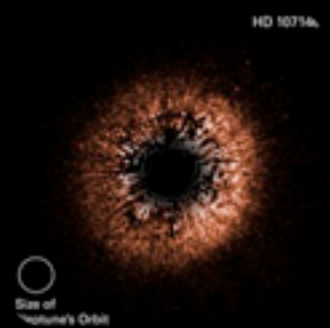
/, 10pc



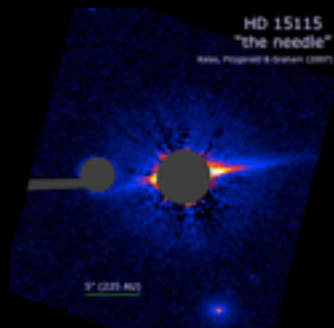


Signal to noise ratio of EGPs at 11μm as a functio of the radial separation assuming a system locate at 10 pc around an M2V star. The dotted and solid lines correspond respectively to the signal to noise ratio in the first and the second filters

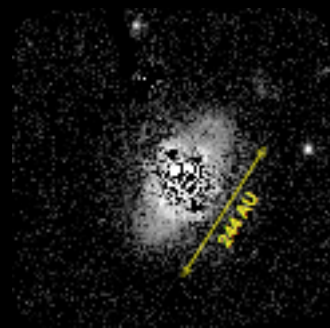
Debris Disks: HST's Legacy



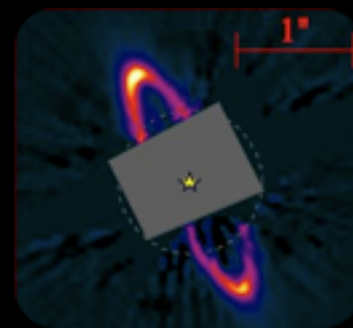
HD 107146
Ardila et al. 2005



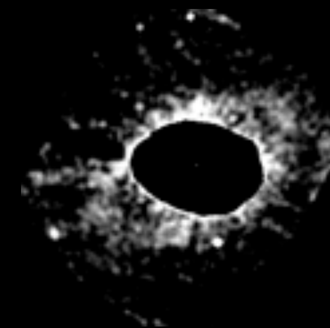
HD 15115
Kalas et al. 2005



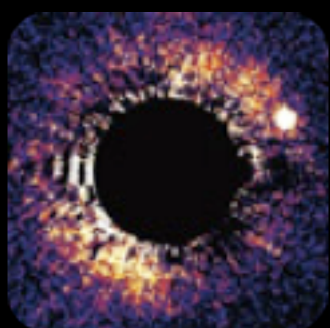
HD 92945
Clampin et al. 2006



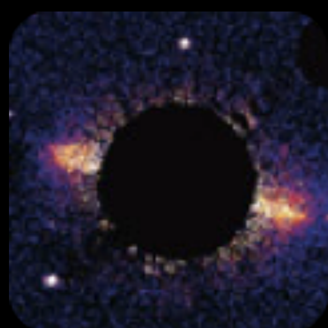
HR 4796
Schneider et al. 1999



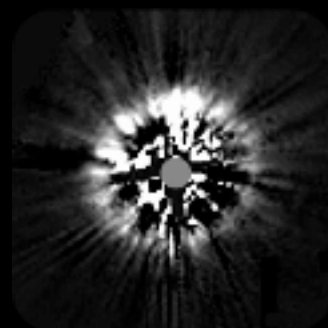
HD 207129
Stapelfeldt et al. 2007



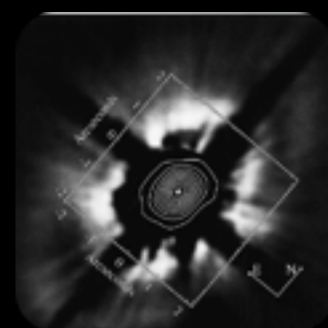
HD 139644
Kalas et al. 2006



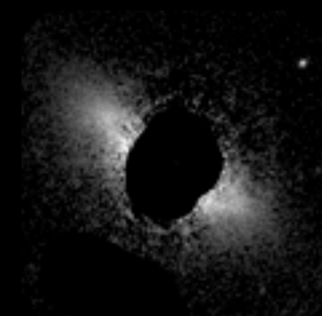
HD 51543
Kalas et al. 2006



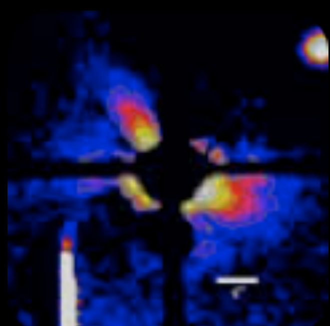
HD 181327
Schneider et al. 2006



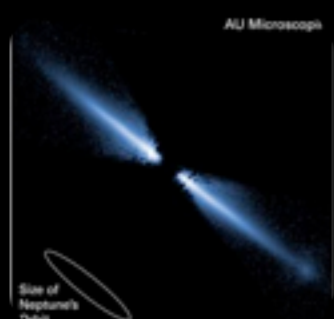
HD 141569A
Weinberger et al. 1999



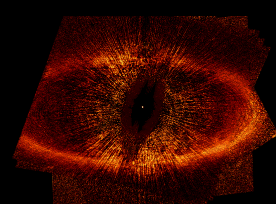
HD 10647
Stapelfeldt et al. 2007



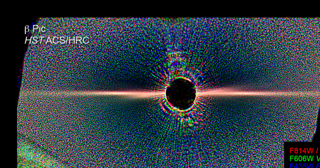
HD 32297
Schneider et al. 2006



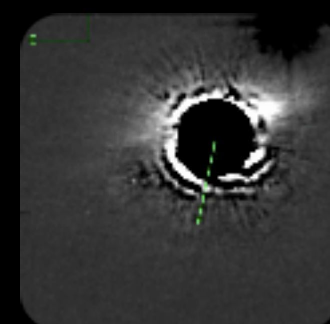
AU Mic
Krist et al. 2005



Fomalhaut
Kalas et al. 2005



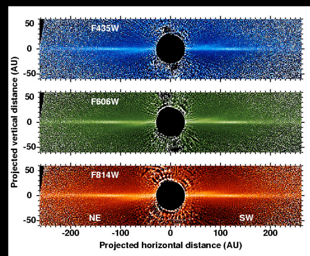
β Pictoris
Golimowski et al. 2005

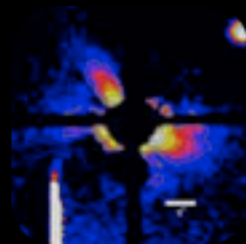


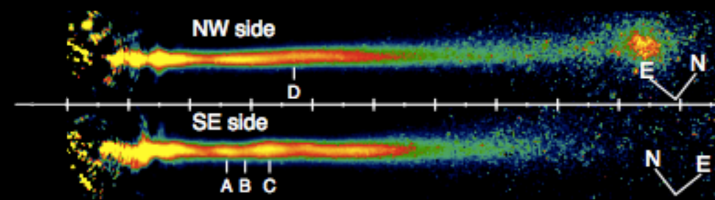
HD 202917
Clampin et al. 2007

Debris Disks: Evidence for Planets

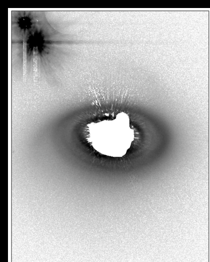
rps



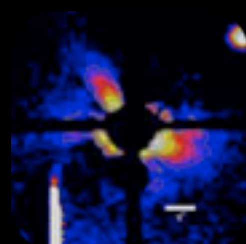


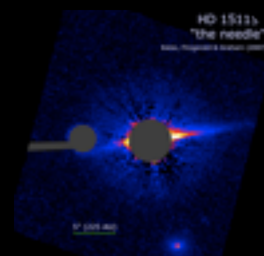


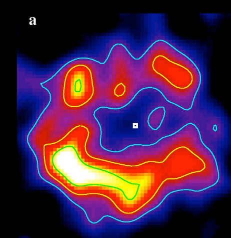
rals



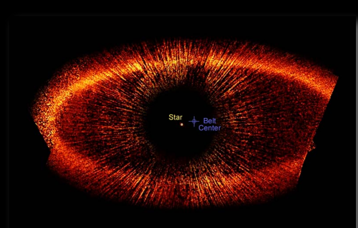
ghtness Asymmetries

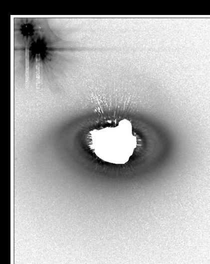


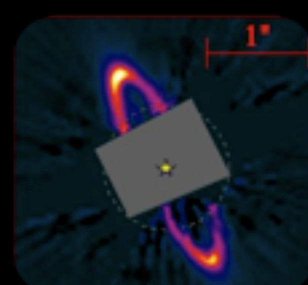




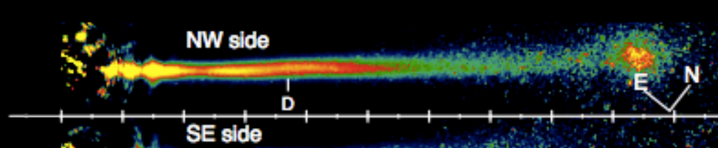
sets

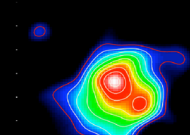


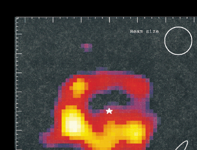


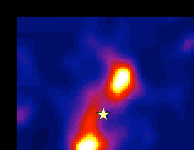


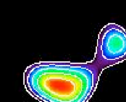
mps





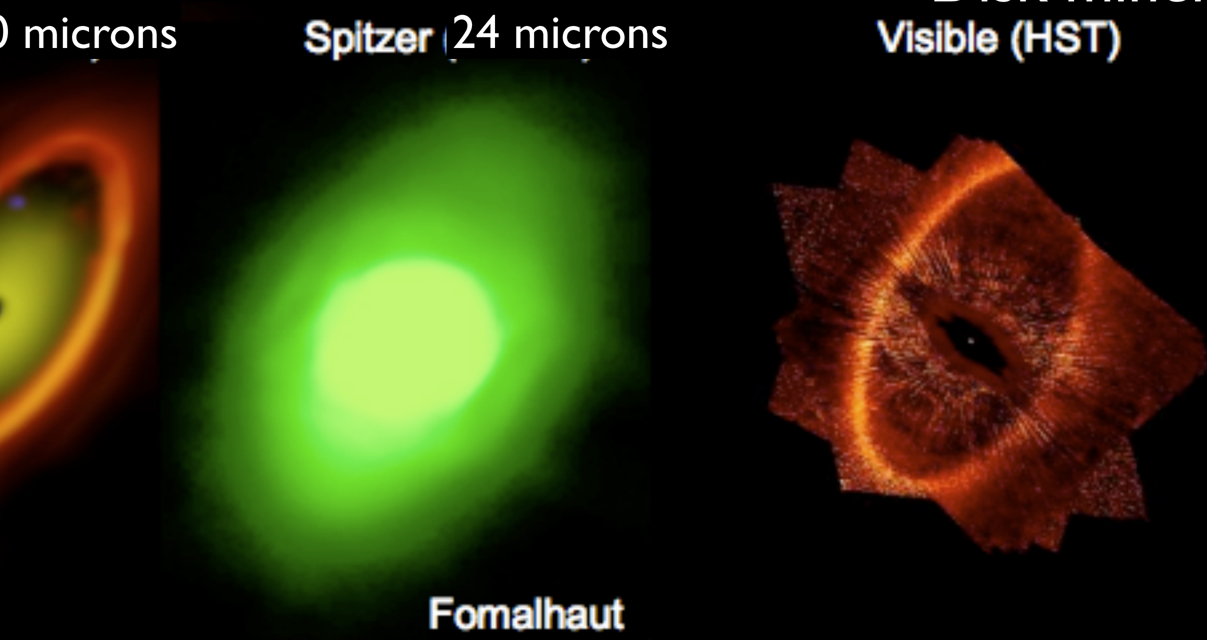


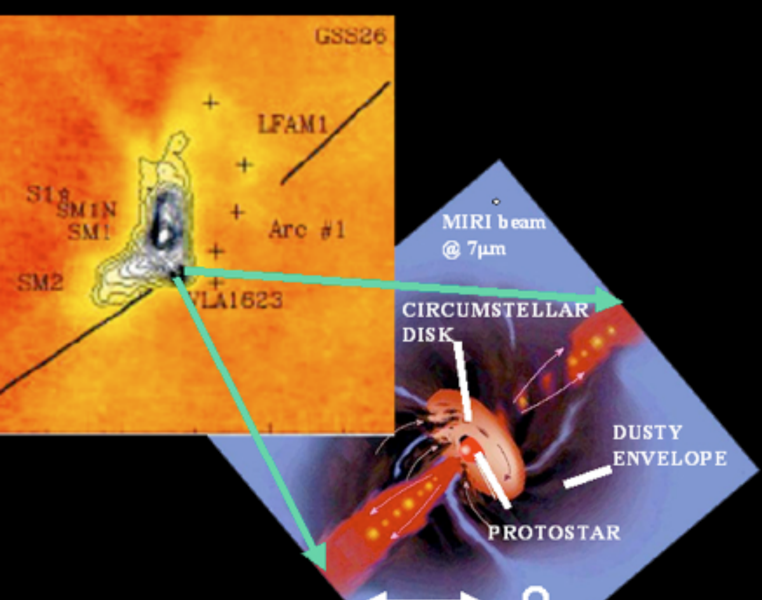


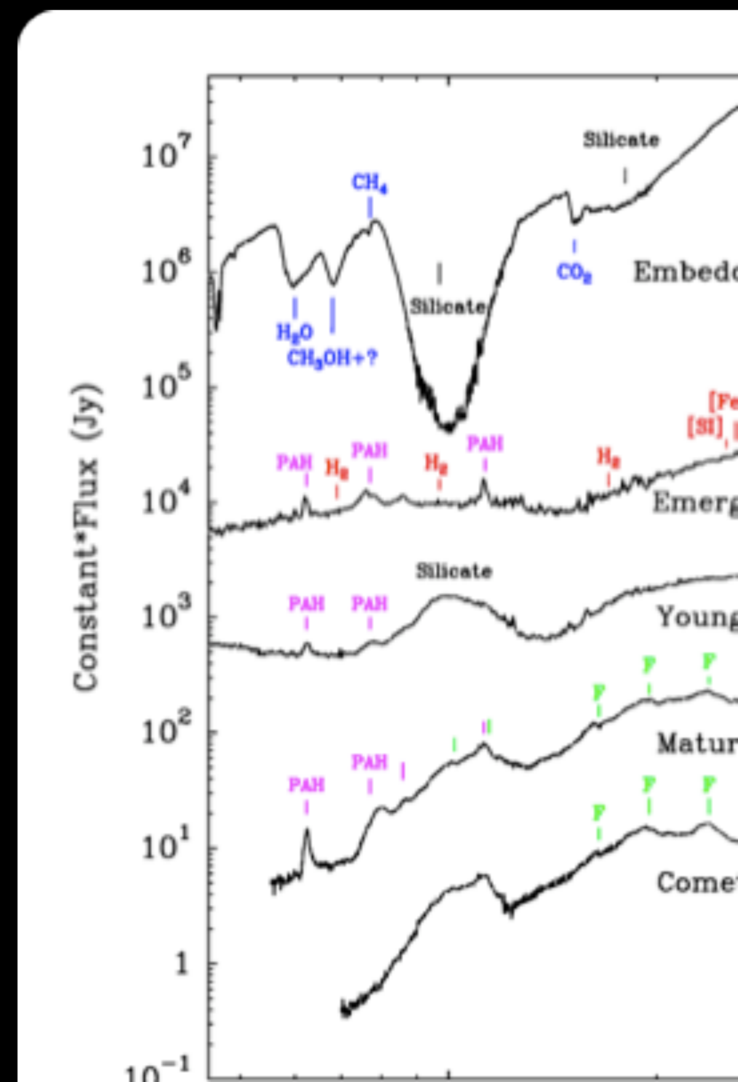


MIRI: Disk Characterization

- Disk morphology: scattered light & emission
- Disk minerology







Summary

JWST is on track for 2013 launch – a major accomplishment!

Predicted performance for exoplanet transits is very good (limited by systematic errors and unknown stability)

3 coronagraphs provided but segmented aperture not optimal

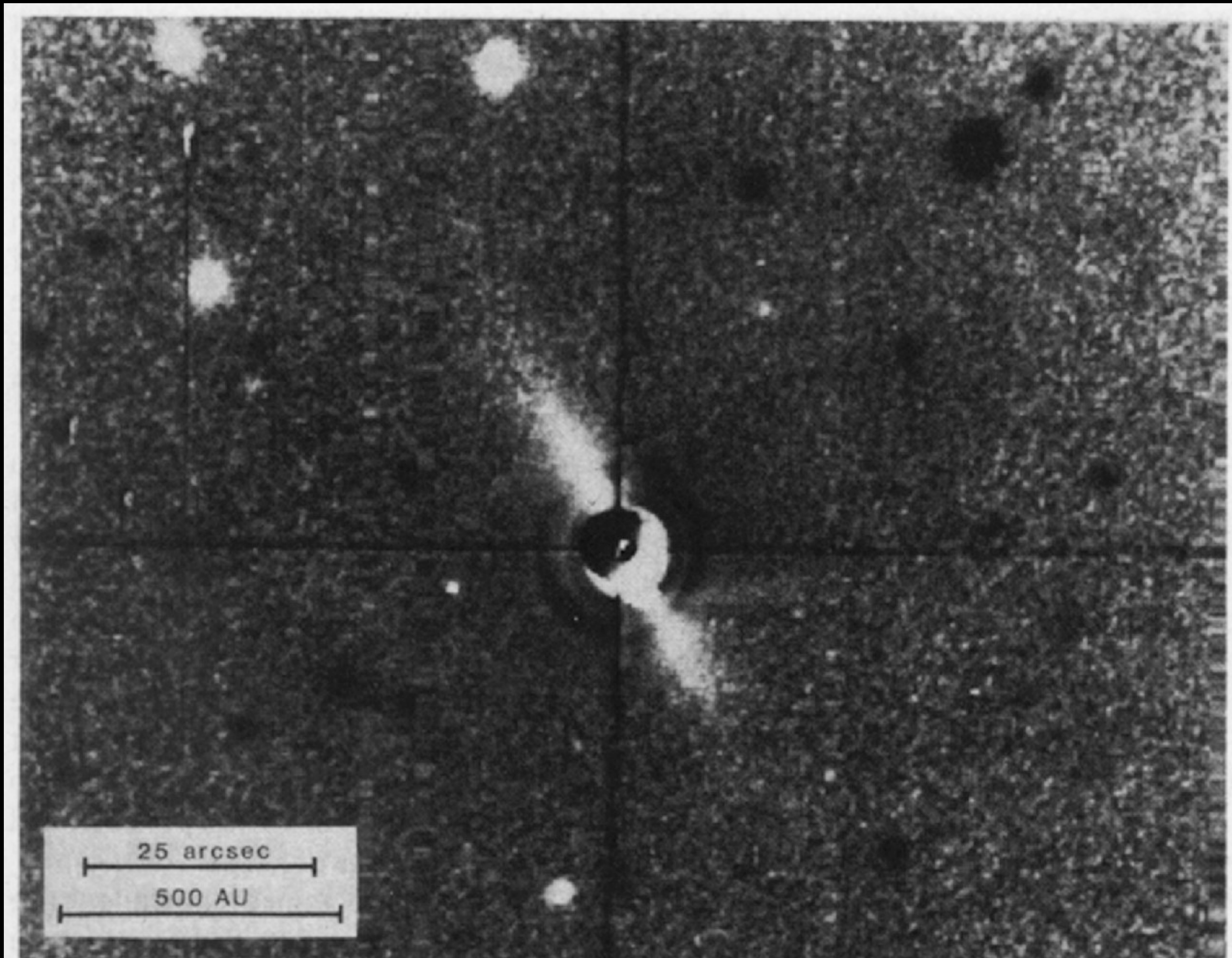
Small changes made for better photometric stability (NIRSpec) and better inner working angle (TFI non-redundant mask)

The End

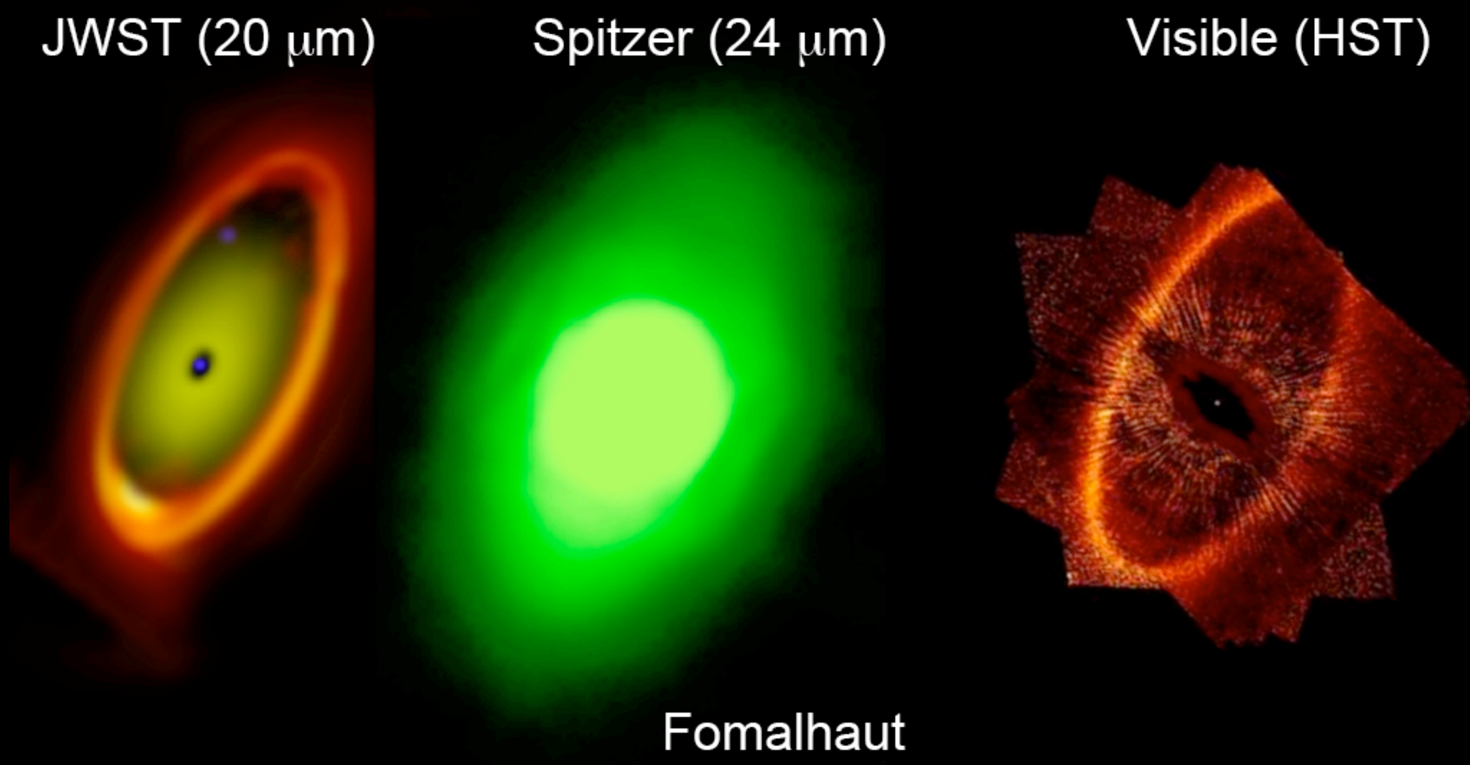
Pluto?

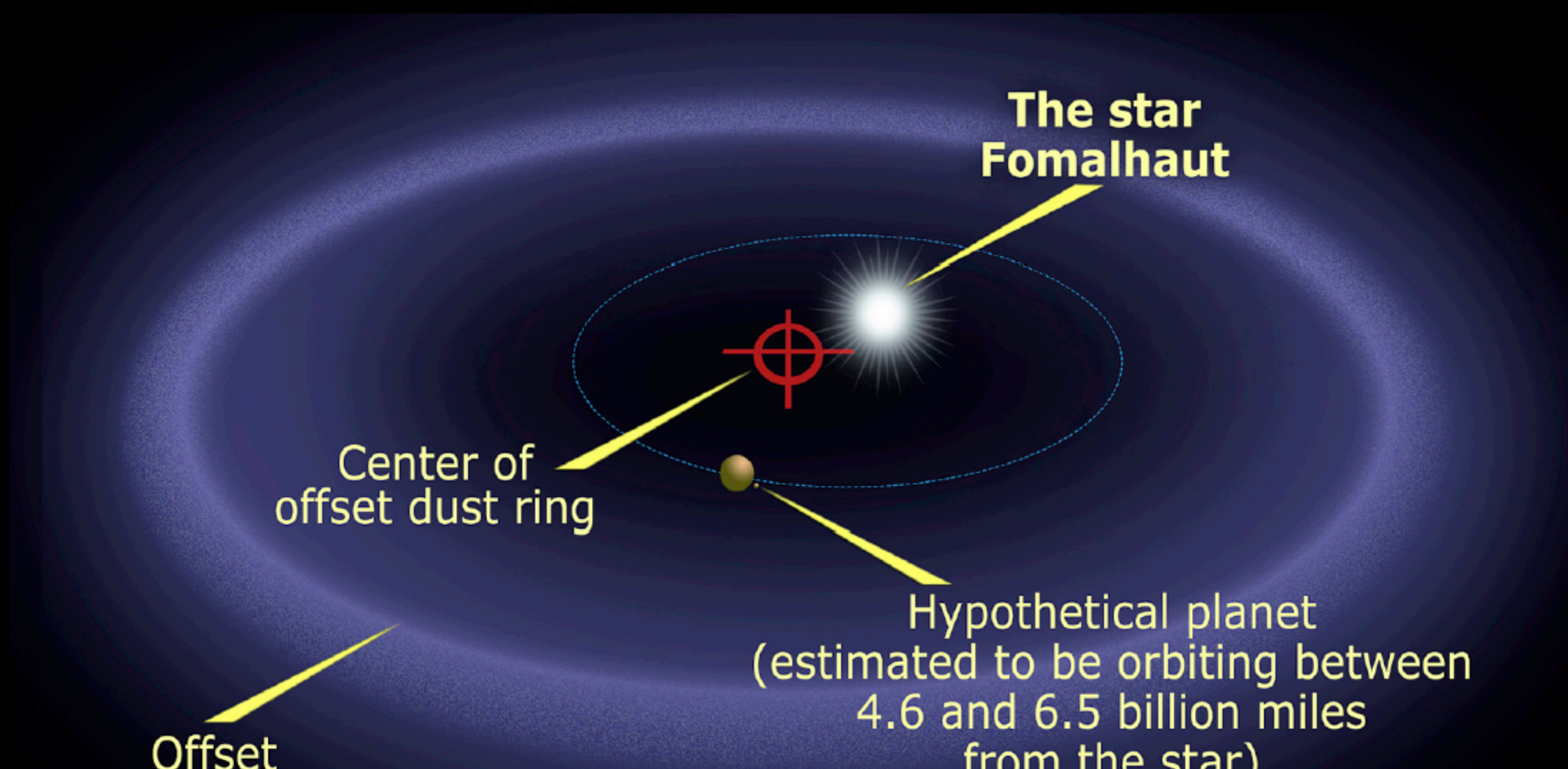

I CAN'T BELIEVE I HAVE TO SIT AT THE "LITTLE PLANETS" TABLE...
PLUTO

Debris Disks: β Pictoris

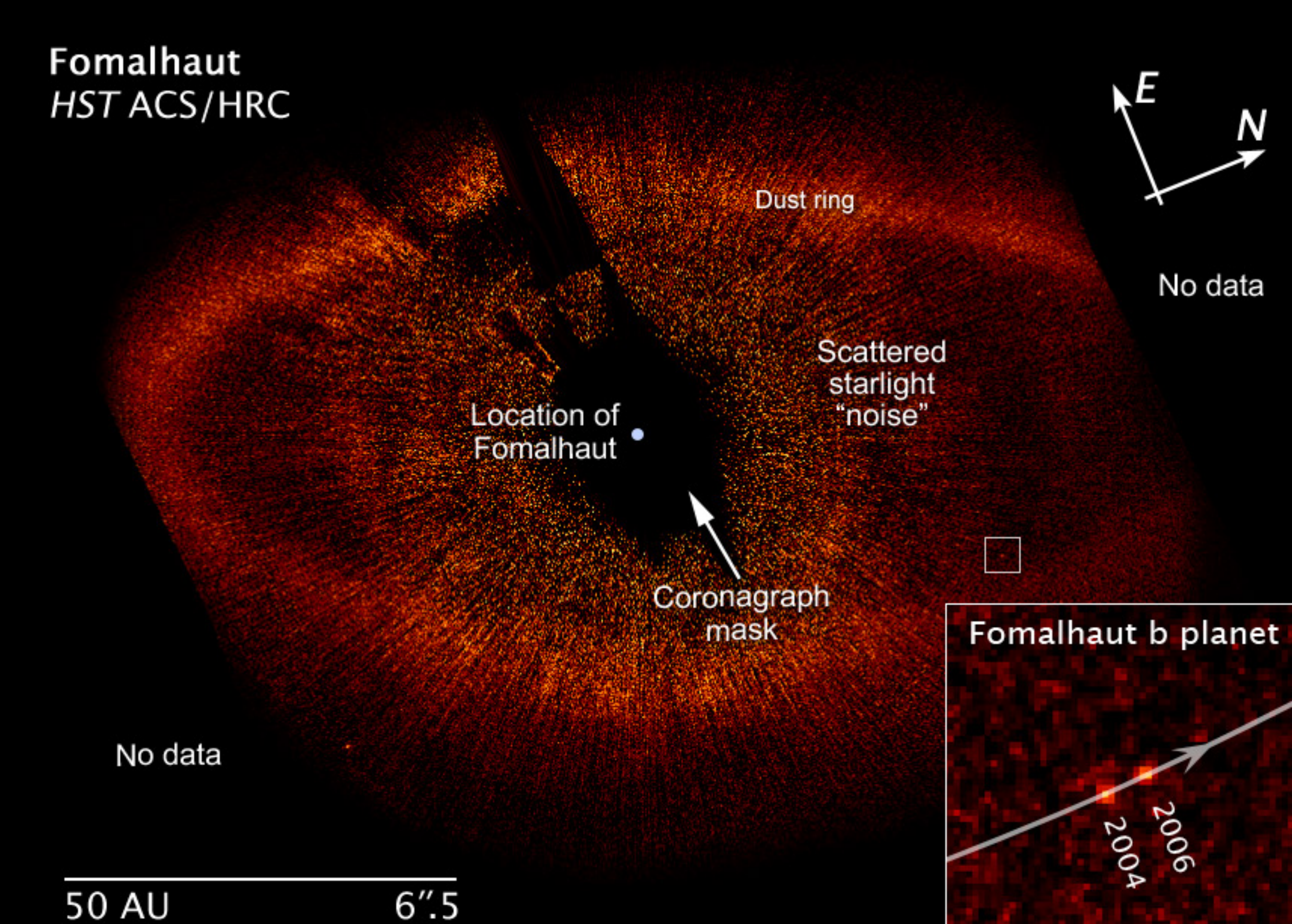


JWST Observations of Fomalhaut





Direct Detection



- **Mark McCaughrean, a JWST SWG member and astrophysicist at the University of Exeter quoted by BBC**
- **"It's like a London bus - you've been waiting for one for ages and suddenly four come along at once."**

- **and more to come!**

Flight Mirror A1